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PHYSIOLOGY.—*The quantum character of light and its implications on visual thresholds.*[1]

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It is indeed a great honor for me to have the opportunity to appear before such a distinguished gathering in the delightful surroundings of this lovely city. I am very grateful to the Washington Academy of Sciences for the invitation extended to me, and wish to take this occasion to offer my sincere thanks.

The retina.—The quantum character of radiant energy absorption by matter was recognized by Einstein in 1905; however, the implications for the field of vision of this important fact were recognized only much later. I want first to sketch very rapidly a picture of the retina, a highly schematic cross section of which is shown in Fig. 1. The sketch on the top shows receptor cells that are called rods and cones. The cones and the rods are all related to synapses which then link up to these bipolar cells. The bipolar cells are linked by other synapses to the ganglion cells, and the axones of the ganglion cells are the fibers that we call the optic nerve. In fact, there are other cells of a horizontal nature whose ramifications extend over something of the order of a millimeter; and there are the so-called amacrine cells whose ramifications don't spread quite so widely, but widely enough to form very complicated connections. So there may be one ganglion cell connected to a single cone, or several cones connected to one single ganglion cell, or several rods connected with one or several cones to a single ganglion cell. This very, very complicated tissue, which is actually an extension of the brain, is only 0.2 or 0.3 mm thick, and we know very little about its function. This is only to give you an idea of the extreme complication of the beginning of the external visual process. The visibility of a test stimulus depends on its spectral composition. The dark adapted eye shows a sensitivity curve which is practically that of the sensitive pigment of the rods, the visual purple or rhodopsin. This pigment seems to be the only one the presence of which in the human eye cannot be denied. The only rod-free region of the retina is a spot 50′ wide called the fovea. The measurement by minutes and degrees of arc is used so that we are not obliged to convert everything into millimeters. By so doing, we can ignore distances between the object used for visual test and the eye. Everywhere outside of the fovea, cones and rods are mingled more or less randomly. The highest visual sensitivity occurs in the periphery of the dark adapted retina.

Rods and cones.—We all learned that rods are generally considered to be much more sensitive than cones; however, Baumgardt has shown, in 1949, that the individual sensitivity of foveal cones is of the same order as that of the rods. In 1954, Arden and Weale confirmed these findings in a more precise manner. The way this kind of experiment is done is as follows:

One chooses a test color and two retinal locations outside and inside the fovea. Since the foveal diameter is only about 50′, one cannot use stimulus sizes larger than this. I used stimulus sizes up to 45′ and I was not able, when doing this type of experiment, to use smaller ones than 5′. Thus, the parameter, the variable of my experiment, was the

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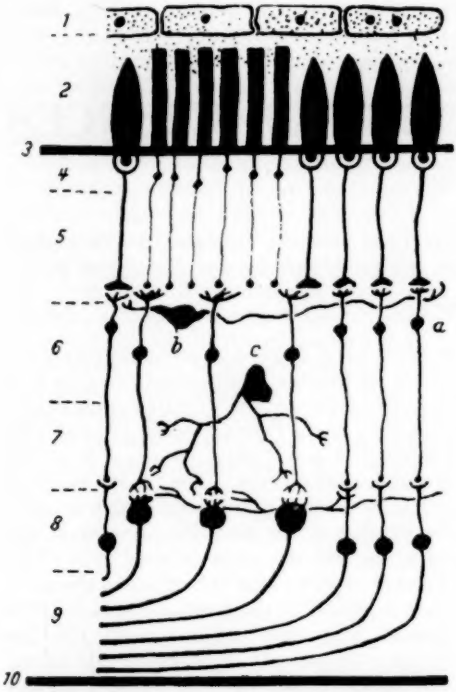

FIG. 1.—The layers of the retina (simplified schematic sketch): 1, Pigment epithelium; 2, cones and rods; 3, outer limiting membrane; 4, 5, nuclei and axones of cones and rods; 6, 7, bipolar cells (*a*), horizontal cells (*b*), amacrine cells (*c*); 8, ganglion cells; 9, ganglion axones, i.e., optic nerve fibers, 10, inner limiting membrane.

size of the test field, varying from 5′ to 45′. I used two retinal locations, one within the fovia and the other 15° outside of the fovea. Then I measured the threshold by the variation of the intensity of light necessary to yield a light sensation in 50 percent of the stimulus presentations. For instance, when presenting a flash of a given intensity 20 times, 50 percent probability of seeing means that the observer, ten times out of twenty, has seen the stimulus. Then, of course, the other 10 times he didn't see anything. Now, establishing the threshold in this manner for stimulus presentations inside the fovea and outside the fovea, it is possible to calculate the threshold quotient, the numerator being the foveal threshold and the denominator the extra-foveal threshold. The quotient obtained for test diameters of about 45′ is 130. When using test spot diameters less than 45′, this quotient turns out to be smaller. It decreases more and more as smaller and smaller spots are used, until finally a diameter of 5′ yields a quotient of only 8. And now, when extrapolating these curves roughly, we find that for very small diameters, this quotient seems to be of the order of one; of the order of one doesn't mean one, but it may be 0.5 or 2; anyhow, it is a small number (Fig. 2). What does that mean? Let us agree that whenever we find that the outer part of the retina, where the rods are the more important units, is more sensitive than the fovea, the reason can not be the intrinsic properties of rods and cones, but it is due to the collaboration of receptors that we stimulate simultaneously. Now we know that the neural connexions are very different in the periphery of the retina from what they are in the center. We know that in the peripheral retina many rods are

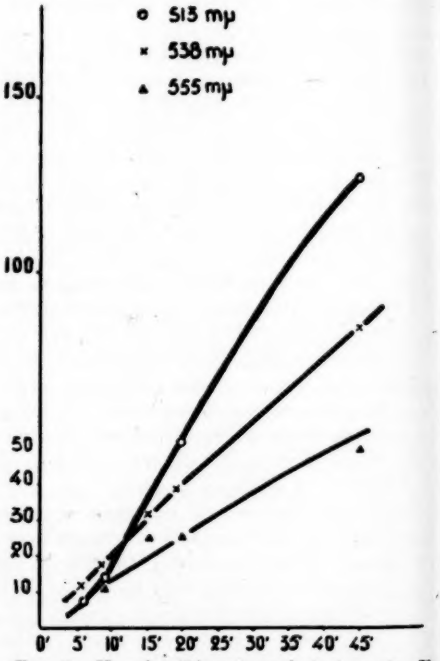

FIG. 2.—X axis: Diameter of test spots. Y axis: Foveal threshold as a multiple of extrafoveal threshold. For small test spots, foveal and extrafoveal thresholds tend toward values of the same order.

linked together with one ganglion cell. This collaboration is largely lacking between the cones in the fovea and that is why rods appear to be much more sensitive than cones, when in fact they are not. When taking in account the volumes of cones and rods, we may state that the sensitivity of their pigments is nearly identical. This is an important point.

Light and quanta.—In 1942, Hecht, Shlaer, and Pirenne determined the smallest light energy necessary to elicit a sensation. They used extra-foveal test spots of 10′ diameter and light of wavelength of 507 millimicrons applied in brief flashes. Measuring the liminal light energy reaching the cornea and taking into account the energy losses of transmission through the cornea and absorption by the light receptors, as well as the pigment epithelium, they found that the necessary radiant energy absorbed by the rod receptors equals roughly 5 to 14 quanta. They proved also that the fluctuations of the sensitivity of the eye at the absolute threshold are due to the quantic and random nature of light. It is a known fact that in an extremely feeble light source, the intensity of which may be controlled with the highest accuracy, there do not exist a constant number of quanta. Thus, in a given flash of 6 quanta *mean* intensity, there may be 5 quanta, or 8, or even as few as 3. One can calculate the probability that a given number of quanta will be absorbed in the receptors during a flash of given *mean* intensity. It turns out that the probability that there will be one quantum absorbed or two quanta absorbed, and so on, can be calculated by resorting to the Poisson distribution, or what is sometimes referred to as the law of small numbers.

Hecht, Shlaer, and Pirenne, in their researches, presented observers with flashes of light. Varying the test brightness randomly for each separate presentation, yields a variation in the frequency with which the stimulus is seen. By this method, they obtained frequency of seeing curves of the type shown in the next slide. This is not an original graph, but it interprets very well the sort of thing that Hecht, Shlaer, and Pirenne did. If we consider a randomly occurring event

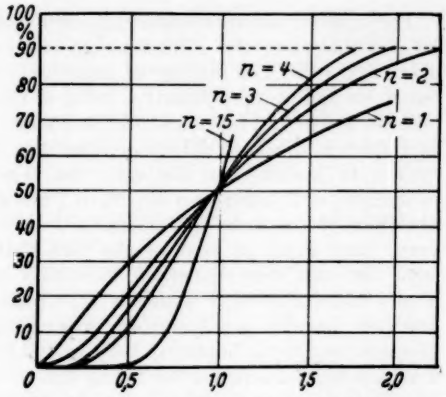

FIG. 3.—Poisson curves. X axis: Multiples of threshold, i.e., 50 percent positive responses yielding value of the independent variable (for instance number of light quanta). Y axis: Proportion of positive responses. *n:* number of aleatory independent events (for instance, number of absorbed light quanta) to be absorbed in order to yield a positive response. With increasing *n*, the slope of the response curve increases. Thus, the slope of the latter is a measure of the number *n*.

and we know only that the number of these events necessary to elicit a response is a small one, then we may calculate the probability that for a given *mean* number of events the response will occur. Thus, in probability of seeing functions, for instance, if 5 quanta are necessary for a light sensation and I provide a *mean* stimulation of 5 quanta, then sometimes 4 will be absorbed, sometimes 5, sometimes more and sometimes not at all. When less than 5 quanta are absorbed, the observer will not see the stimulus; when 5 or more than 5 quanta are absorbed, he will see it. Such Poisson curves are shown in Fig. 3. One of these curves is a plot of n, which means that only 1 random event is necessary for the elicitation of a response. Here are also curves for n 2, n 3, n 4, and n 15. One notices that the slopes of these curves become steeper as the number n increases. In an experiment such as that performed by Hecht, Shlaer, and Pirenne, they compared their experimental curves with Poisson curves such as I am showing you, and they found that the slope of the experimental curve varied between n's of 5 and 7. There were three observers; for one of them the n was 5; for the other, 6; and for a third it was

7. They used a test spot whose diameter was 10′. In this case, the retinal image covers about 500 rods. The number of quanta necessary to elicit a light sensation being of the order of 5, 6 or 7, it becomes clear that visual excitation in this case did not require that 2 quanta be absorbed in the same rod. The probability of 2 quanta out of 5, 6, or 7 being absorbed by the same rod would have been very, very small in view of the fact that some 500 rods were concerned. Now that is a very important fact! It means that when one rod absorbs one quantum, something happens; and what happens? Very probably a local potential arises in the retina and several of these local potentials will yield a light sensation by a complex process about which we do not have entire and complete knowledge, but the beginning of which we know from a large number of experiments in electrophysiology. This important result closed Hecht's investigations on the quantum relationships in visual threshold.

The studies in vitro by Schneider, Goodeve, and Lythgoe showed, in 1939, that the quantum yield in the bleaching of visual purple, the light-sensitive pigment of the rods called rhodopsin, is independent of the wavelengths of stimulation over a wide part of the spectrum, and that it is probably unity, which means that no secondary reaction will lead to further rhodopsin molecules being bleached as the result of the initial absorption of one quantum. One quantum will bleach one molecule of rhodopsin.

The two-quantum theory.—In 1944, Van der Velden published a paper on the probabilistic theory of threshold vision. He showed that n, which is the number of quanta absorbed to reach the threshold level, must be two. In this case, and this case only, the index which characterizes the area effect for red light and for large extra-foveal stimuli can be shown to be equal to 0.5. The basic type of experiment employed here is the following one: Using a given wavelength of light, a given duration time, and a given retinal projection (location of the stimulus), the variation of the diameter of the test spot is the only parameter. When the diameter of the test spot increases, its retinal image increases likewise. One measures the threshold brightness; i.e., the mean brightness of the test spot, that produces 50 percent of positive responses, and then one may plot a function of threshold intensity versus diameter. In the peripheral retina this type of experiment always produces the following results: In deep red light, the relation $A^{0.5} \times I = \text{const.}$ called square root law is found to hold where A is the area and I the intensity of the light (flux per unit area). One finds that this relation holds for all test spots subtending angles of more than 6′ approximatively. In any light other than deep red, this relation holds only for tests or test spots subtending angles of more than one degree. When testing near the fovea, this value decreases and is, for example, only about 20′ at 7° out of the fovea.

This is one type of area effect observed. Since 1947, Baumgardt has treated the same subject from essentially a physiological point of view. He emphasizes that n cannot be equal to 1. The absorption of one single quantum cannot determine a light sensation because if it did there could not be any area effect. The sensitivity would not depend on the diameter of the test spot, whether it is big or small. If one single quantum were sufficient to elicit a sensation, there could not be any law relating one size of test spot to another. So we know that n must be greater than 1. By one kind of experiment, we find n equal to 2; by another, we find n equal to 4, or 5, 6, 7, or sometimes even a little bit more. For test stimuli smaller than those to which the square root law applies, a full integration law applies. This means that for very small test diameters, the law becomes $A \times I = \text{const.}$ and this is true for red light everywhere outside of the fovea and for test spot diameters of less than 6′. It is also true for any light other than deep red light for test spot diameters smaller than about 1°, except very near the fovea where these values change somewhat because the neural structure of the retina is changing rapidly in that region.

In a region of about 15° to 20° outside the fovea, which is called by Polyak the "near Periphery", where most of the measures of this sort have been done, rods and cones form clusters of about 100 units, the number

of cones being about $\frac{1}{30}$ the number of rods. Every cluster is linked through the bipolar cells to a little ganglion cell whose ramification spreads over about 4′ diameter. If we make the very reasonable assumption that every local potential provoked in the receptor by quantum absorption cannot reach any ganglion cell except that to which its cluster is linked, then the full integration law means that when there are a certain number of light quanta absorbed in such a unit, this will yield a constant response whatever the spot in which they are actually absorbed. If this is a quasi-independent unit, this means it is a unit where ramifications of one ganglion cell allow neural responses to collect. Now, if say 5 of those local responses are necessary, it doesn't matter where inside this spot the 5 nervous responses arise. Local responses arise to form propagated action potentials. Experiment shows in fact that whenever the diameter of a red test spot is raised over 4′ or 6′ which is just approximately the diameter of a little ganglion cell's ramifications, the threshold energy begins to increase and that means that the number of quanta to be absorbed at the threshold of vision increases. This happens because now only a part of the light quanta necessary to elicit a propagated action potential and, by the way, threshold light sensation, can be absorbed in a given quasi-independent unit.

Call n the number of quanta the absorption of which in quasi-independent units is required at the threshold of vision. Call the number of stimulated quasi-independent units k, and call q the number of quanta absorbed in this stimulated area. Then compute the probability for n quanta or more to be absorbed. The statistical calculation[2] for which no hypothesis whatever nor any parameters are used, yields the following function: $A^{0.5} \cdot I = \text{const.}$, the area A being proportional to the number k of units composing it. What about the number n? Any visual experiment done with the condition that the test size used corresponds to more than one quasi-independent unit, yields the square root law (as I showed you before) $A^{0.5} \times I = \text{const.}$ with a very good approximation—even an excellent approximation! This yields so high an accuracy and has been tested by so many investigators, that there can be no possible doubt. Thus, the number of quanta to be absorbed in one unit to yield a light sensation, must be equal to 2. There always exists this apparent contradiction—this discrepancy with respect to response curves—and I will come back to this point.

With peripheral test stimuli of any colour other than red, Graham and Margaria, as well as Baumgardt, observed the constancy of test energy—that means the full integration law—for areas whose diameter does not exceed about 1°. This means that the responding quasi-independent units must spread over about 1°. But does such a unit exist? It does indeed. It is a giant ganglion cell described by Polyak who assigned to it a mean ramification diameter of about 70′. It is the same type of unit the spikes of which have been reported by Granit in the cat's retina, as shown by Rushton in 1949. We know that it covers about 10,000 to 20,000 rods and about 200 to 300 little ganglion cells in the retina of man. For test areas larger than 1°, the square root law applies, as was shown by Graham and Margaria for test diameters up to 3°, and by Baumgardt for test diameters up to 8°. Thus, it is highly probable that 2 quanta absorbed in any quasi-independent unit yield a nerve impulse or a volley of impulses reaching the visual cortex. Since the rods are practically insensitive to extreme red light of wavelength higher than 670 millimicrons, the absorption of that quanta takes place in the red receptors. Owing to the neural organization of these latter, the absorption of the 2 quanta must take place inside a given cluster. This cluster has about 100 units, 3 of which approximately, are extra-foveal cones, and the nerve impulse is limited to the small ganglion cell associated with this cluster. On the other hand, for a neural network of rods incorporating about 200 clusters associated with the ramifications of a single giant ganglion cell, the full integration law holds for test spots of 1° diameter for all but extreme red radiations.

Improved quantic theory.—I cannot discuss

[2] See Appendix.

here the important effects related to duration of stimulation. Let me just mention briefly that the absorption of light quanta must take place during a definite time interval for the greatest efficiency. If the duration of the stimulus is more than some critical interval which depends upon retinal location, test colour and spot size, then the threshold energy increases. Quantum considerations enable us to predict certain time effects in a manner similar to the one that I have demonstrated relative to area effects. There remains one major problem—one space law and one time law of threshold vision point towards $n = 2$, whereas nearly all the response curves yield values of n of the order of 4 or 5 or so. This dilemma is only an apparent one as was shown in 1952 by Baumgardt.

Anyone who has measured visual thresholds knows that there are very great individual fluctuations. One may note variations of n from 4 to 7 within the same observer, and there are marked differences between the mean n's obtained by different observers. There is much evidence for the view that such variability is not of a retinal, but instead, of cortical origin, because an untrained observer yields higher n values than he does later when he has been trained. This must mean that psychological conditions similar to attention, feeling and so on affect the threshold. So I am assuming that the two-quanta hypothesis applies strictly to the retina, but that possibly more than one pair of quantum absorptions may be necessary for a perception. We must prove in this case that the theoretical area- and time-laws would be the same as in the case of a rigorous two-quanta hypothesis.

We know that the area effects, or the time effects as well, all argue for $n = 2$, but on the other hand, we derive from experiments n's which are larger than 2—say 5, for instance. Let us make the assumption that to yield a sensation there must be absorbed 2 quanta by a quasi-independent unit, but that this must happen twice or three times. Projecting stimulus test spots which cover, say, 10 quasi-independent units, 2 quanta absorbed in one of them give rise to a propagated nerve potential. But, we may suppose that this does not necessarily elicit a light sensation and that possibly another nerve potential must arise by the absorption of 2 other quanta in the same or another of these units, and, maybe, even by a third pair of quanta. Therefore, it may be that 2, 3, or 4 action potential are necessary to elicit a light sensation; but when we make this assumption, we must prove not that it is true—for we cannot prove that—but we must prove that it is compatible with the facts. Well, to do this, we need only to prove mathematically that such a scheme would yield the same area law as that obtained when assuming the absorption of only 2 quanta.

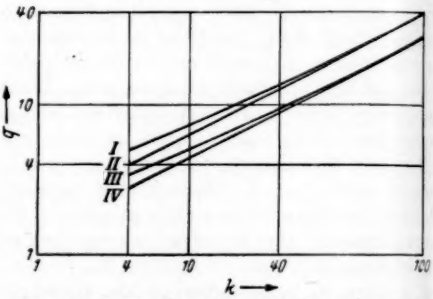

FIG. 4.—*k:* Number of quasi-independent units stimulated. *q:* Number of quanta to be absorbed in order to yield a 50 percent probability for threshold excitation. I under the assumption that three quanta (the first and the second forming one pair and the second and the third another pair) or four quanta forming two pairs are to be absorbed in order to yield a cortical threshold response. III under the assumption that one pair is sufficient. II and IV the square root law $A^{0.5} \times I = \text{const}$ (Piper's law). The latter, i.e., the observed figures are practically indistinguishable from the calculated figures I and III, especially with increasing k, that is, with larger stimuli.

I did this calculation and I found that this is really with a very good approximation of the case (Fig. 4). I calculated such a law for the case where not 2 quanta, but 2 pairs of quanta are to be absorbed (or 3 quanta during a time interval such that the first and the second, as well as the second and the third are to be considered as pairs), and you see that the curves it yields are practically identical to those of the square root curve. Here, the greatest difference that we may note is less than one tenth of a logarithmic unit, and that is the case for $k = 4$, or, in other words, for a very small test light. When the test spot is much larger then, you

see, the curves become identical. *This means that from our experiments we cannot decide if we are concerned with one double quantum absorption or with several double quantum absorptions; and so it has been proved that there is no contradiction between the quantic explanation of the square root law on the one hand, and the quantic explanation on the frequency of seeing curve on the other.* This is an important point because it gave rise for years and years to discussions that were sometimes quite violent. We may state that it is difficult not to ascribe this square root area law or this square root time law to the existence of a retinal mechanism implying the spatially and temporally limited coincidence of two chance events. It is hard to believe that these events do not invoke neural potentials caused by the absorption of light quanta. On the other hand, we know that a threshold response generally does not require the absorption of much more than about 4 or 5 quanta. We must conclude that the 2-quantum theory applies correctly to the retina and that the foregoing hypothesis allows for the variability of liminal quantum absorption number n; and thus, *experiments on the quantum theory of threshold vision are consistent.*

Adaptation problems.—Van der Velden and Bouman have published a number of papers concerning the results of contrast contours of very different types which were discussed from the point of view of the 2 quanta theory. One of the most important features of their results is the following: The quantum number n increases with increasing background brightness. When the eye is adapted to a certain luminous level and we select a spot on the background and at this spot add a certain known brightness, and then ask the observer to say if he has or has not detected the increment, the n obtained in this manner increases with increasing background brightness and seems to reach a constant value of about 20 at low photopic brightness levels. This must mean that the quantum demand increases so that now 20 quanta must be absorbed instead of 2, in order to yield a propagated nerve impulse or a volley of such impulses. At these levels the probability of absorbing a quantum is the same as it is at threshold and the bleaching of rhodopsin is practically nonexistant and may be neglected. One would like to interpret this fact by means of a neural inhibition effect probably located in the retina. I shall come back to this point.

The question arises as to whether the quantum theory of vision can account for the mechanism of dark adaptation. The first suggestions concerning an improvement of Hecht's photochemical theory which assumes that dark adaptation is entirely due to the accumulation of visual purple in the rods, seem to have been made by Lythgoe in 1940. He suggested that a part of light adaptation might be due to the reduction of retinal summation. In 1943, De Vries pointed out that because of the inevitable fluctuation around the mean number of quantum absorbed in a given time and in a given area of the retina, the differential threshold for brightness must necessarily increase as intensity level is raised, even if the amount of photo-sensitive substance in the retina remains constant. In 1948, Rose published a paper that related the sensitivity performance of the human eye to an absolute scale. The author considered that the limits of precision of every visual process are determined partly by fluctuations of different order, especially physiological processes. *His treatment of the differential threshold shows clearly that one cannot reasonably imagine theories of vision which dispose arbitrarily of excitation thresholds of different retinal receptors and of photochemical reactions.* Dr. Jones will probably review in detail this very interesting work. Rose's discussion covers the adaptation range between absolute threshold and 2,000 trolands. This means normal light at room level. He proved that for this very, very large range, the variation of concentration of the photosensitive pigment must be less than a factor 10, whereas the variation of the sensitivity of the retina is a very large figure of the order of ten thousands. Thus, the bleaching of rhodopsin cannot account for the extraordinary sensitivity of vision in this large range.

In 1948, Baumgardt showed that when adapted to a brightness of 1/1,000 ml, or about 1,000 times the threshold of brightness, the differential intensity threshold is about 100 times the absolute threshold.

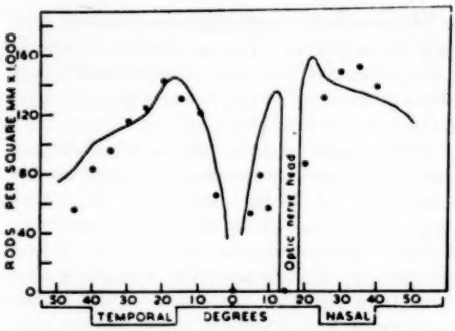

FIG. 5.—The points are Rushton's figures of rhodopsin density measured in the living human eye. The curve represents Østerberg's figures of rod density in a horizontal meridian of the human retina.

However, calculations show that this background brightness corresponds to the absorption of less than 1 quantum per rod per second; thus it appears that rhodopsin concentration is practically constant even up to photopic levels, for every rod contains about 20,000,000 molecules of rhodopsin. Even if during light adaptation there were no regeneration of rhodopsin at all, there would be less than 50 percent loss of sensitivity after 5 minutes adaptation to a brightness of about 30 ml, which represents normal room lighting levels whereas the loss really observed is more than 99.99 per cent. Rhodopsin concentration cannot control the sensitivity of the eye up to moderate photopic levels. How then do we explain that the area effect is a function of the adaptation state of the eye, for it is as has been proved by a large number of scientists, such as Bouman, then Doeschatte, Baumgardt, Arden and Weale, and Pirenne? For the time being only the assumption that dark adaptation is essentially a neural phenomenon seems to provide an adequate interpretation of the experimental results. Since 1952, Rushton has published several papers on the measure of rhodopsin concentration in the living eye. Unfortunately, time is too short to allow a description of his ingenious apparatus and the details of his work.

Fig. 5 shows rhodopsin density that he measured along the horizontal meridian of the human retina. There appears to be an exact parallelism between the rod density as measured by Østerberg, and the rhodopsin density as measured by Rushton. Fig. 6 shows the time course of regeneration in the retina of man. Time is plotted along the X axis from the beginning of dark adaptation, and the Y axis shows the percentage regeneration of rhodopsin lost by foregoing light adaptation. In fact, this slide shows that after 7 minutes dark adaptation following an intense light adaptation period, rhodopsin is already regenerated to 50 percent, whereas the rod threshold reached is very, very far from having this level in so short a time.

Conclusion.—Let me now sum up very rapidly by giving some brief general conclusions about what we know in this field. The supporters of a classical photochemical theory of vision, for instance, Mote, Riopelle, and Meyer, 1950, state that the process of dark adaptation is entirely due to the accumulation of rhodopsin in the rods. This assumption being incompatible with the fact that in the scotopic range the rhodopsin concentration remains practically constant, George Wald suggested in 1954 that very small variations of rhodopsin concentration may provoke important sensitivity variations, as a result of the laminar structure of

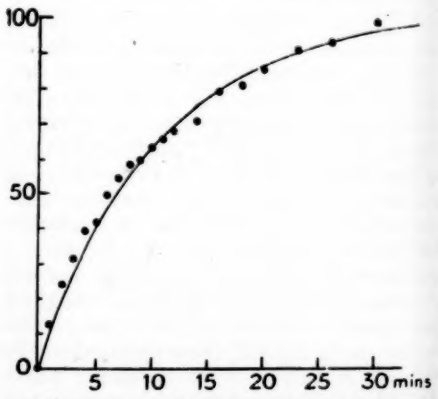

FIG. 6.—X axis: Time in minutes after offset of a light adapting stimulus. Y axis: Percent of regenerated rhodopsin as measured by Rushton in the dark-adapting human eye. Seven minutes after onset of dark-adaptation, 50 percent of the rhodopsin decomposed by light adaptation are regenerated. Thus, the threshold should have fallen to twice the final dark adapted level, if rhodopsin density alone is concerned. But, in fact, the measured threshold at 7 minutes after offset of the adapting stimulus is many hundred times greater than the final value.

the rods. His really very ingenious hypothesis has however been proved to be inconsistent with the experiments and he abandoned it. The supporters of a neural photochemical theory object that even improved, photochemical theories are unable to explain the area effect, receptor field size variations during dark adaptation and meta-contrast. I cannot explain in detail this very interesting effect, but Kuffler's work on neural responses of the intact cat's retina has demonstrated the neural character of this effect, studied especially by Fry, Piéron, and by Fry and Alpern. The purely photochemical theories, say supporters of neuro-photochemical theory, cannot explain why contrast threshold decreases during several minutes of strong light adaptation as shown by Baker in 1949. (Fig. 7.) When we adapt ourselves to intense light, we should think, according to the exclusively photochemical theory of light adaptation, that our threshold would increase immediately—but it does not. It decreases first for 3′ and then increases. One would think that the first part of the curve is due to a neural effect and the second part due to bleaching of a photosensitive pigment, as shown in Fig. 7. The supporters of a neural, photochemical theory also invoke the fact that very slow adaptation is observed for other sense organs—the ear, for instance, where no photochemical nor any comparable process can take place, and where slow neural processes seem to be the only explanation for the time being. None of the supporters of the neural, photochemical theory has so far proposed a complete numerical scheme because our knowledge of nervous processes in the retina is very incomplete. The synthesis of their suggestions, which takes into account quantum relations —the authors quoted as being Lythgoe, De Vries, Ségal, Rose, Baumgardt, Van der Velden, Pirenne, Aguilar, Bouman and ten Doeschatte, Rushton, Piéron, and Weale—yields a picture of the light adaptation processes measured by increment thresholds that seems to follow a pattern, the essential features I shall resume. Let me point out clearly that this is a research program rather than anything else. Its only goal can be to show that it would be prudent to try to understand light adaptation not only from the point of view of the photo-sensitive relations, but to take into account effects due to the underlying nervous structure and related to quantum effects. This very, very rough picture should give only an indication of the paths which might be used to seek out new facts—not new theories. Of theories there are enough.

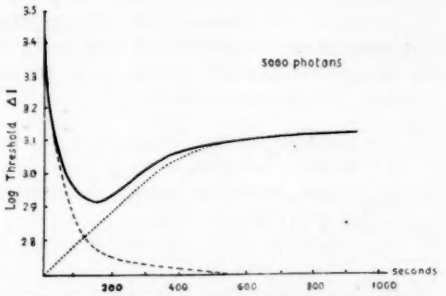

FIG. 7.—Howard D. Baker's figures for differential threshold variation as a function of time of exposure to an adapting field: ———. Possible explanation of this time curve by simultaneous action of photochemical decomposition: · · · and of decreasing nervous inhibition i.e., decreasing glare: – – – –

The increased noise in the visual system contributed by quantic fluctuation is dependent on the number N, the number of absorbed quanta. The amount of noise will always be proportional to the square root of this number; thus, if 1,000,000 quanta are absorbed in a given time in a given area, there will be a mean fluctuation of about 1,000. There will always be such a fluctuation, which must necessarily increase the differential threshold because the brain cannot follow this fluctuation—otherwise a stable impression would be impossible—and so there must be nervous mechanism that regulate this perception. After this effect has been set up—and it is set up at lowest levels—adaptation begins. A nervous inhibition decreases the cadency of action potentials delivered by the ganglion cells, and decreases the size of the quasi-independent units. During this stage quantic fluctuation continues to act, as well as at later stages, and pupil contraction appears which also is a barrier to limit the number of light quanta entering the eye. At mean photopic levels, or even higher, photochemical bleaching begins and becomes important at the

level of 1,000 to 10,000 trolands. At such levels the bleaching of the photosensitive pigment remains the last and the most efficient barrier against extreme physiological light intensities, which otherwise might provoke too intense a neural activity and thus cause injury.

APPENDIX

CALCULATION OF PROBABILITY OF QUANTA ABSORPTION AS A FUNCTION OF THE NUMBER OF QUASI-INDFPENDENT UNITS AND TOTAL NUMBER OF QUANTA ABSORBED.

n minimum number of quanta to be absorbed in receptors to reach threshold.

N *average* number of quanta absorbed in receptors during a flash.

q number of quanta absorbed in receptors during a *given* flash.

$q < n$ the flash is not seen

$q \geq n$ the flash is seen

$P_{N,q}$ probability for q quanta to be absorbed during a given flash, N being the mean number of absorbed quanta.

$\sum_{q=n}^{\infty} P_{N,q}$ probability for a flash to be seen.

k number of stimulated quasi-independent units.

$\frac{k!}{(k-q)!}$ number of combinations allowing for only 0 or 1 quantums out of q quanta being absorbed in each of k quasi-independent units.

k^q number of possible combinations.

$P_{k,q} = 1 - \frac{k!}{k^q(k-q)!}$ probability for 2 or more quanta to be absorbed in at least one unity

$P_{k,q}$

at threshold:	k	2	$8 = 2^2 \times 2$	$50 = 5^2 \times 2$	$200 = 10^2 \times 2$	$800 = 20^2 \times 2$
$0.5 = \frac{k!}{k^q(k-q)!}$	q	2	$4 = 2 \times 2$	$10 = 5 \times 2$	$20 = 10 \times 2$	$40 = 20 \times 2$
	P_{kq}	0.5	0.599	0.618	0.626	0.629

The probability of seeing $P_{k,q}$ is shown to be nearly constant if $k > 2$ and I proportional to $\sqrt{k}$.

This means that the area A—which is proportional to the number k of stimulated quasi-independent units it contains—is related to the threshold flash intensity I by the formula $A^{0.5} \times I = \text{const}$.

This is the so called Piper's law which is effectively observed in all experiments. Thus, the quanta hypothesis succeeds to predict a law whose existence has never been explained before; and to do so, it does not use any arbitrary or derived parameter.

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GEOLOGY.—*A study of the montmorillonite variety galapektite*,[1] GEORGE T. FAUST, U. S. Geological Survey.

(Received March 29, 1957)

HISTORICAL

Clay mineralogy is unfortunately beset with a multitude of names, many ill-defined, others misapplied and some assigned to one or more of the well-established clay mineral species. Galapektite is one of the names that has been applied to two different mineral species. It is the purpose of this paper to review the previous usage, add some new data on analyzed material from the type locality, and recommend discontinuance of the name by relegating it to the synonomy.

Breithaupt (1832) introduced the name "Galapektit" with the following description[2]:

> Species: Galapektit—Breithaupt. Resembles heavy cream; so called halloysite.* Compact masses with a conchoidal fracture, and commonly with cracks. Greasy feel. Luster waxy, becoming shining in the streak. Streak white. Color white in blue and green shades. Transparent on thin edges becoming more so, after being placed in water.
> H = 2¼ to 2¾, sometimes soft.
> G = 2.128 (from Angleur).
> G = 2.142 (from Bannat—with native copper).

Breithaupt was accordingly completely aware that two different clay minerals were present at Angleur in Belgium, the one halloysite, the other the mineral he called galapektite.

Le Chatelier (1887) examined a series of clay minerals by means of a technique hitherto unusued in the identification of clays, namely, thermal analysis. The sample of clay mineral from Angleur studied by Le Chatelier is definitely identified as halloysite by the chemical analysis in Table 1 (Number 1) and his dehydration study. Le Chatelier did not call this clay by the name galapektite but considered that he studied halloysite.

Dana (1892) states that galapektite is the halloysite of Angleur and quotes the analysis of Le Chatelier. There is a misprint in his description where the spelling galapectite is used.

Hintze (1897) follows Breithaupt and draws attention to the observation of two different clay minerals at Angleur.

Brendler (1912) refers to galapektite as white-greenish white to gray-white masses from Belgium.

Ross and Kerr (1934) in their study of halloysite and allophane investigated galapektite. They examined specimens of halloysite from the type locality Angleur, Liège Province, Belgium, and also galapektite from Angleur. They identified galapektite as montmorillonite on the basis of optical examination and noted that "X-ray diffraction patterns of galapektite also agree with patterns of the type montmorillmite".

Strunz (1941) stated that galapektite is probably identical with halloysite.

TABLE 1.—CHEMICAL ANALYSIS OF HALLOYSITE AND MONTMORILLONITE VARIETY GALAPEKTITE FROM ANGLEUR, 2 KM SOUTHWEST OF LIÈGE (LÜTTICH), BELGIUM, AND OF A MONTMORILLONITE FROM MISSISSIPPI

Mineral	Halloysite	Galapektite	Montmorillonite
Constituent	Analysis #1	Analysis #2	Analysis #3
SiO_2	46.3	50.86	50.39
Al_2O_3	39.5	18.76	17.37
Fe_2O_3	—	2.07	2.84
FeO	—	n.d.	Trace
MgO	—	3.48	4.56
CaO	—	1.76	1.29
Na_2O	—	[0.37]	.46
K_2O	—		.04
H_2O^-	[14.3]	n.d.	13.31
H_2O^+		22.34	10.11
TiO_2	—	Trace	—
Total	100.1%	99.64%	100.37
Analyst	Henri Le Chatelier	John G. Fairchild	R. E. Stevens
Notes	H_2O below 250°C = 8.5%		

[1] Publication authorized by the Director, U. S. Geological Survey.

[2] A free translation is included here because Breithaupt's book is not generally available.

* Under the name of halloysite, from the same locality, Angleur near Lüttich (Liège), I have found two remarkably different minerals."

Ross and Hendricks (1945) published an analysis of the galapektite from Angleur, Belgium and computed its formula to be

$$\frac{(Ca)}{2}\ 0.17$$
$$\uparrow$$
$$[Mg_{.39}\ Fe_{.11}^{3+}\ Al_{1.56}]\ [Si_{3.88}\ Al_{.12}]\ O_{10}\ (OH)_2$$

Hey (1950) comments that galapektite is a "synonym of halloysite, but some specimens are montmorillonite."

In summary it seems that Breithaupt (1832) was clearly aware that two different minerals occurred at Angleur, one halloysite, the other he named galapektite. Le Chatelier (1887) studied and reported on the halloysite from Angleur and in his work makes no mention of galapektite. Ross and Kerr (1934) and Ross and Hendricks (1945) found both halloysite and galapektite in specimens from the type locality. It was apparently Dana (1892) who confused the nomenclature by correlating Le Chatelier's halloysite with the name galapektite of Breithaupt. Dana also used two spellings for the locality, Angleur and Anglar, and the latter, which is erroneous, has unfortunately crept into the literature of clay mineralogy.

My colleague Clarence S. Ross turned over to me some of the material used for the chemical analysis and suggested that I study it by DTA and X-ray methods.

DESCRIPTION AND CHEMICAL ANALYSIS

Galapektite. Locality, Angleur, Liége Province, Belgium. Sample prepared by C. S. Ross for analysis. Color pinkish buff (Ridgway). U. S. Nat. Mus. no. 4777. Analysis 2 in Table 1.

Montmorillonite. Locality, Husband farm, Lemon, Smith County, Miss. Sample prepared by C. S. Ross for analysis. Dense, translucent material, olive-buff (Ridgway) in color. Bentonite. Analysis 3, in Table 1.

These two montmorillonites are nearly identical in chemical composition and typical of montmorillonite. Their formulas further express their similarity:

Galapektite
$$\frac{Ca}{2}\ 0.17$$
$$\uparrow$$
$$[Mg_{.29}\ Fe_{.11}^{3+}\ Al_{1.56}]\ [Si_{3.88}\ Al_{.12}]\ O_{10}\ (OH)_2$$

Montmorillonite
$$\frac{Ca}{2}\ 0.14$$
$$\uparrow$$
$$[Mg_{.51}\ Fe_{.16}^{3+}\ Al_{1.44}]\ [Si_{3.86}\ Al_{.14}]\ O_{10}\ (OH)_2$$

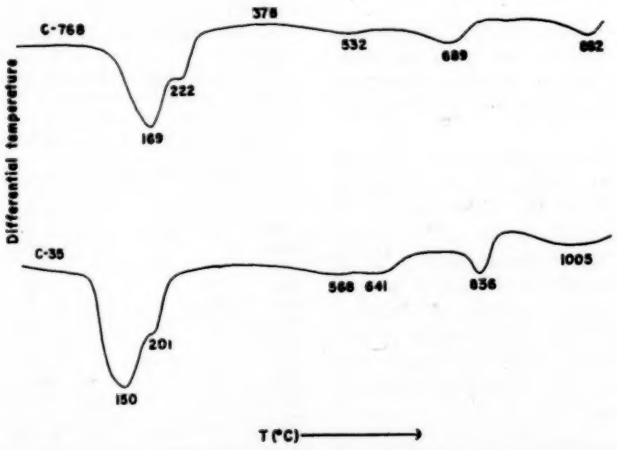

FIG. 1.—Differential thermal analysis curves for galapektite C-768, and montmorillonite from Lemon, Miss., C-35. The temperature on the left of the diagram is about 25°C, the temperature at the termination of the curves, on the right, is about 1000°C.

TABLE 2.—OBSERVATIONS ON THE THERMAL ANALYSIS CURVES[1] OF GALAPEKTITE AND MONTMORILLONITE

Mineral	Record no.	Temperature of Troughs and Peaks °C							Locality	Weight of sample used (grams)
		Low temperature			Intermediate temperature		High temperature			
		Endothermic		Exothermic	Endothermic		Endothermic			
Galapektite	C-768	169	222	378	532	689	882		Angleur, near Liège, Belgium	0.4231
Montmorillonite	C-35	150	201	Present	568	641	836	1005	Lemon, Smith County, Miss.	0.4774

[1] These curves were obtained with a resistance of 600 ohms in the galvanometer circuit.

DIFFERENTIAL THERMAL ANALYSIS

The differential thermal analyses were made in a modified form of the Alexander, Hendricks, and Nelson (1939) apparatus. The samples were heated at the rate of 12°C per minute. The records were obtained as photographs.

The DTA curves of galapektite and a typical montmorillonite are given in Fig. 1 and the data are summarized in Table 2. The close similarity of the two curves is apparent and galapektite is thus a member of the montmorillonite group.

X-RAY STUDIES

The X-ray data were obtained from powder patterns and from a diffractometer record. The results are given in Table 3. The spindle for the powder patterns (prepared by R. C. Erd U.S.G.S.) were made with ethyl cellulose. Filtered iron radiation was used in preparing the X-ray powder photographs. The diffractometer pattern (prepared by John C. Hathaway, U.S.G.S.) was made with filtered copper radiation.

The patterns were indexed by the method of Brindley (1951). The *b* parameter was calculated from the 06 reflection. The data are given in Table 3. The agreement between the calculated and observed values for the d spacings is satisfactory. A faint line at 3.36A composed of spots is attributed to quartz.

A sample of galapektite was soaked in ethylene glycol and a diffractometer pattern prepared. The 00l reflection was registered as a practically symmetrical peak at 17.0A. The other 00l spacings observed were d_{002} = 8.50, d_{003} = 5.60, d_{005} = 3.37A. The values of d_{003} calculated from these data are 17.0, 16.80 and 16.85A respectively. The presence of this integral sequence of basal reflections indicates that there is no interlayering in the structure.

A powder pattern of galapektite that had been fired in the DTA furnace (C-768) showed a number of broad and diffuse lines which correspond with the pattern of spinel ($MgAl_2O_4$). According to the studies of Bradley and Grim (1951), this is the phase that would be expected to develop in the sample.

CONCLUSION

The DTA and X-ray studies described in this paper show clearly that galapektite is a member of the montmorillonite group. It is comparable to the montmorillonite from

TABLE 3.—X-RAY POWDER-DIFFRACTION DATA FOR GALAPEKTITE (Fe/Mn; λ = 1.937A)

Indices	d(A)	I	d(A) Calcd.	Notes
~001	15.1	vs	—	
~003	5.0	m	—	
11,02	4.48	vs	4.49	
~004	3.75	f	—	diffuse
~005	3.01	m	—	
13,20	2.56	s	2.59	very broad
15,24,31	1.696	w	1.698	
06,33	1.498	s	1.498	assumed
26,40	1.288	w	1.297	broad
17,35,42	1.246	vw	1.246	

Lemon, Smith County, Miss. and is a typical dioctahedral montmorillonite. Since there is nothing unusual about this mineral to warrant the continued use of the name galapektite, it is proposed here to relegate the name galapektite to the synonomy and to call it and minerals nearly identical with it, montmorillonite.

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GEOLOGY.—*The relation between lattice parameters and composition for montmorillonite-group minerals.*[1] GEORGE T. FAUST, U. S. Geological Survey.

(Received March 29, 1957)

The existence of a relationship between the lattice parameters and composition of the montmorillonite group minerals was sought by Brindley and MacEwan (1951) (in Brindley, 1951). They confined their study to the layer parameters a and b, and in particular to b since $a = \frac{b}{\sqrt{3}}$, and developed equations for calculating b from the composition of a montmorillonite when expressed in the formula for one half the content of a unit cell. Brindley and MacEwan (1953) reconsidered their equations of 1951 and presented more precise relationships. These were discussed again by Brindley (1955), and he gives the following formulas for calculating the lattice parameter b:

For dioctahedral minerals

$b = 8.90 + 0.06x + 0.09q + 0.18r + 0.27s$

For trioctahedral minerals

$b = 9.18 + 0.06x - 0.12p - 0.06q + 0.06s$

where

x = number of Al for Si substitutions in tetrahedral positions

p = number of Al atoms in octahedral positions

q = number of Fe^{3+} atoms in octahedral positions

r = number of Mg atoms in octahedral position

s = number of Fe^{2+} atoms in octahedral positions and

$p + q + r + s = 2$ for dioctahedral positions

$p + q + r + s = 3$ for trioctahedral positions

I have published X-ray powder data for some analyzed members, of unusual composition, of the montmorillonite group and it is of interest to see how the observed values of the parameter b compare with

[1] Publication authorized by the Director, U. S. Geological Survey.

those calculated from the formulas of Brindley and MacEwan. These minerals are griffithite from Griffith Park, Los Angeles, Calif. (Faust 1955); iron saponite from Cathkin, County Lanarkshire, Scotland (Faust 1955); stevensite from Springfield, Union County, N. J. (Faust and Murata 1953), which are classified as trioctahedral montmorillonite and the variety, galapektite, a dioctahedral montmorillonite (see preceding paper).

The computed values of the parameter b and the observed values for these minerals of the montmorillonite family are given in Table 1 along with the data for talc and pyrophyllite as given by Brindley and MacEwan (1953).

Brindley (1955) has pointed out that the dioctahedral montmorillonites have a value of d_{06} less than 1.52A whereas the trioctahedral members have a d_{06} value greater than this. The data given in Table 1 for the observed and calculated value of b correspond very well.

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TABLE 1.—MEASURED AND CALCULATED VALUES OF THE b PARAMETER FOR SOME MONTMORILLONITE-GROUP MINERALS

Dioctahedral	d_{06}	b (obs)	b (calcd)
Pyrophyllite $[Al_2][Si_4]\,O_{10}(OH)_2$	1.484 (060)	8.90	8.90
Galapektite $[Mg_{.39}Fe_{.11}^{III}Al_{1.56}][Si_{3.88}Al_{.12}]O_{10}(OH)_2\cdot\frac{Ca}{2}\cdot 17$	1.498	9.01	9.01
Trioctahedral			
Talc $[Mg_3][Si_4]O_{10}(OH)_2$	1.515 (060)	9.10	9.18
Stevensite $[Mg_{2.88}Mn_{.02}Fe_{.02}^{III}][Si_4]O_{10}(OH)_2\cdot\frac{Ca}{2},\frac{Mg}{2}\cdot 15$	1.526	9.16	9.18
Saponite (Iron) $[Mg_{2.29}Fe_{.26}^{II}Fe_{.45}^{III}][Si_{3.19}Al_{0.75}Fe_{.06}^{III}]O_{10}(OH)_2\cdot\frac{Ca}{2}\cdot 20$	1.543	9.26	9.22
Griffithite $[Mg_{1.88}Fe_{0.52}^{II}Fe_{0.44}^{III}Al_{0.04}][Si_{3.19}Al_{0.81}]O_{10}(OH)_2\cdot\frac{Ca}{2}\cdot 25, Na\cdot 11$	1.541	9.25	9.23

The newest is but the oldest made visible to our senses.—THOREAU.

ECONOMY IN THE PLANNING OF EXPERIMENTS

One of the typical problems confronting both the experimental scientist and research worker in industry is that of evaluating the joint effects of several different factors on a given material or process. Other things being equal, the smaller the number of factors the fewer the difficulties encountered. Because of possible complex interactions among the various factors, however, the difficulties become formidable for even a relatively moderate number of factors. Problems of this kind have often had to be dismissed as too difficult, although occasional brilliant results were achieved by scientists gifted with unusual insight or sound judgment gained through long experience. The recent growth of the subject of experiment design has occurred in response to the need for more systematic and reliable methods, a need created by the growing scope and complexity of scientific and industrial activity.

The first broad classes of experiment designs, made possible by advances in statistical theory, were devised to fit the special problems of agricultural research. Somewhat later, efforts were made to adapt these experimental procedures for use in physical science, engineering, and industry. At the National Bureau of Standards the study of these problems forms a major part of the research program of the NBS Statistical Engineering Laboratory. The latest results obtained by the Laboratory, in research supported partly by the Chemical Corps, Department of the Army, should lead to material savings in time and effort for experimenters faced with multifactor problems. These results, which relate to an important class of experiment designs, are described and catalogued in the NBS publication *Fractional factorial experiment designs for factors at two levels.*[1]

One way to approach a multifactor problem is to make measurements with all factors except one fixed, and afterward to repeat this process for each of the factors. Conclusions are then drawn concerning the effect which each factor has on the measurements. When the various factors are interdependent, however, the "one factor at a time" procedure may lead to erroneous results. R. A. Fisher[2] has shown that the most efficient way to conduct multifactor experiments is to make measurements at all possible combinations of the factors involved.

Nevertheless, even for a relatively small number of factors, the number of possible experimental combinations may more than tax the available facilities. Also, in many situations it is not practical to plan an entire experimental program in advance, but rather to conduct a few smaller experiments which serve as a guide to future work. Or, more generally, it may be that not all of the information or precision which a complete set of experiments could give is needed for the purpose in hand.

Several statisticians, notably Finney and Kempthorne,[3] have recently considered the problem of planning multi-factor experiments that require measuring only a fraction of the total number of possible combinations. The experiment designs that have resulted are known as "Fractional Factorial" designs. These not only save experimental effort, but they also make the analysis relatively straightforward.

The result of the Bureau's studies along these lines has been to make the theory of fractional designs more immediately accessible to the working scientist. The new publication, prepared by the Statistical Engineering Laboratory,[1] catalogues experiment designs in which the number of factors range from 7 to 16, with all factors allowed two different conditions. For problems with these general characteristics, the experimenter can choose from among procedures requiring only $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, $\frac{1}{128}$, or $\frac{1}{256}$ or all possible experimental combinations.

An industrial chemical process, for example, may depend on the commercial grade of the principal reactant, the source from which the reactant is obtained, the amount and concentration of acid used, and the pressure, temperature, and time of reaction. Suppose it is desired to study the effects on the characteristics of the

[1] *Fractional factorial experiment designs for factors at two levels.* Nat. Bur. Standards Applied Math. Ser. 48 (in press). Available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

[2] *The design of experiments*, by R. A. Fisher. Edinburgh, 1949.

[3] *The fractional replication of factorial arrangements*, by D. J. Finney. Ann. Eugenics **12**: 291, 1945. *A simple approach to confounding and fractional replication in factorial experiments*, by O. Kempthorne. Biometrika **34**: 255, 1947.

final product when these seven factors are varied; and assume that it is sufficient to consider only two alternatives in connection with each factor, so that there are two commercial grades of reactant, two concentrations of acid, and so forth. Since there are seven factors and each may exist in two different conditions, there are 27 or 128 possible experimental combinations. A "complete factorial design" would prescribe the making of all 128 of these experiments.

However, it may not be practical to perform all of the experiments. Possibly, also, one may not need all the information such a complete factorial procedure could provide. It is at this point that assistance may be obtained from the experiment designs described in the Bureau's publication.

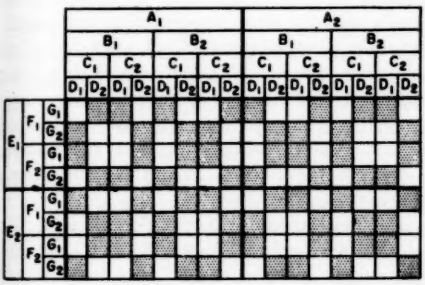

FIG. 1.—Fractional factorial experiment plan designed by NBS scientists, requiring only 64 of the 128 possible measurements.

In the example given, let the letters A, B, C, D, E, F, G stand for the seven factors, and let the subscripts 1 and 2 denote the two alternative conditions in which each of the factors may exist. Then the 128 possible experimental combinations are represented by the 128 cells of Figure 1. The shaded squares represent those experimental combinations to be investigated if the experimenter wishes to measure only half of the possible 128 combinations. In the same way, Figs. 2 and 3 illustrate plans requiring only 36 and 16 measurements, respectively, instead of the full set of 128.

Naturally, the more measurements taken, the greater the resulting information and the greater

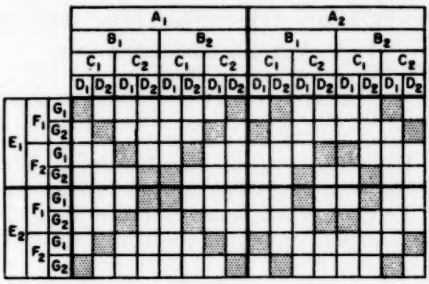

FIG. 2.—Fractional factorial experiment plan designed by NBS scientists, requiring only 32 of the 128 possible measurements.

the precision. The experimental plan calling for ⅛ of the possible combinations can only be used for evaluating the broad effects of each of the seven factors. The ¼-plan, in addition, allows the interdependence of some of the factors to be determined. The latter plan could be of use, for example, when there is independent information indicating that the interaction between certain of the factors is negligible. The ½-plan (Figure 1), on the other hand, not only provides information on the broad effects of each of the seven factors, but also permits evaluation of the interdependence among *all* of those factors. The only price paid for this information is a loss in precision. In many cases, especially in industrial experiments, this loss is more than compensated for by the saving in time and expense.

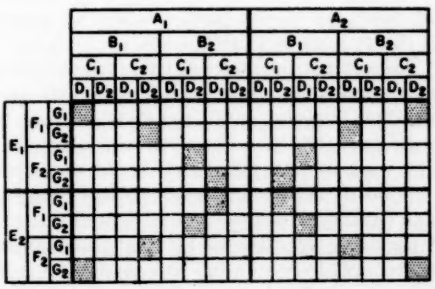

FIG. 3.—Fractional factorial experiment plan designed by NBS scientists, requiring only 16 out of 128 possible measurements.

ENTOMOLOGY.—*The stridulations of some crickets in the Dominican Republic.*

H. A. ALLARD, Arlington, Va.

(Received April 5, 1957)

While residing in the Dominican Republic from November 3, 1945, to February 7, 1946, and again from September 10, 1947, to January 29, 1948, for the purpose of collecting insects and plant material for the Smithsonian Institution, I was always much impressed with the insect sounds around me. There were many new and distinctive cricket notes, but there was rarely any great din of blending insect music such as one hears in August around Washington, D. C., when large colonies of snowy tree crickets, *Oecanthus niveus* DeGeer, and the true katydids, *Pterophylla camellifolia* Fabricuis, become musical.

In the Dominican Republic when the warm and humid evening arrives, scattered chirping and tinkling notes issue from the shrubs and trees here and there. Some of these are clear, incisive little points of high-pitched sound; others are powerful, penetrating, buzzing, almost ringing noises, continuous and even very disconcerting to many people because of the incessant din.

In the capital city, Ciudad Trujillo, the large brown cricket *Anurogryllus muticus* (DeGeer) is very common and noisy throughout the winter. As soon as night came on and lights appeared, these ubiquitous crickets began their activities out-of-doors in the yard and even within the wide-open houses, for there are no screened windows or doors in the typical Spanish houses.

The song of the males of this cricket, here, is a continuous ringing z-z-z-z-z-z of tremendous volume and penetration which practically fills a room with veritable din. The song is quite like that of our common cone-head, *Neoconocephalus robustus crepitans* (Scudder) of the eastern United States. After being accustomed to hear the trilling notes, definitely musical in tonality, of our American individuals of this species, I was somewhat nonplussed to hear this tropical cricket singing continuously, with all the characteristics of a cone-headed katydid, and with no tonality in its stridulation. I kept a close eye on this common, ubiquitous species, and one evening I thought I heard weak fluttering notes produced by a female of the species perched on a jutting coral rock entering into the construction of the outer wall of the house or portico. I very carefully studied this cricket, for it was not very wary, and sure enough this female also had musical inclinations. Spreading the elytra slightly it expanded the long membranous underwings and set them in rapid vibration, thus producing a weak fluttering sound. These sounds were probably never consciously heard by ordinary untrained ears. A life-long association with the musical habits of Orthoptera made it consciously audible to me at once.

My first acquaintance with *Anurogryllus muticus* was early in June 1941 at Clarendon, Va., across the Potomac River from Washington, where I had located a large colony in a pine grove here. The crickets of this colonly appeared to be more or less arboreal and were always seen on the trunks of the pines from one foot to eight feet above the ground. Their stridulation, which I described in a paper "Some Musical Orthoptera at Clarendon, Virginia," Can. Ent. **48:** 356-358, 1916, was nothing like that of individuals of this species stridulating in the Dominican Republic. The Virginia crickets, it is true, stridulated with a continuous "song," but it was a high-pitched trill with a definite tonality, and at first lead me to believe it was the trilling of a tree cricket, *Oecanthus nigricornis* or *O. nigricornis quadripunctatus*. Why many of our crickets and katydids stridulate so differently in different regions of their range has never been satisfactorily explained, although such variations of behavior have been more than once observed. Weak musical impulses by the females have been given some attention, and it is known

[1] The writer is indebted to Dr. Ashley B. Gurney of the Entomology Research Branch of the United States Department of Agriculture for all identifications.

that the females of many species, perhaps generally, produce weak, almost inaudible sex calls, for the males in the vicinity appear to be exceedingly sensitive and alert to these. I have heard the females of various species of katydids make their distinctive clicks, and have noted males flying toward their position at once. This notifying click or snap of the females, rather than the incessant chirping and buzzing of the males, appears to be the most distinctive call-note functioning to bring the sexes together. I have never seen the females particularly interested in the ceaseless noisy demonstrations of the males, but often I have seen the males flying in from all directions when a female of the species delivered her weak, alluring wing-clicks.

On the night of December 10, 1945, at Ciudad Trujillo, I ran down an intermittent, high-pitched tinkling chirp localized in the foliage of an Ixora bush (*Ixora coccinea* L.). This cricket proved to be a species of *Orocharis*, probably *O. similis*, as tentatively identified, owing to insufficient knowledge of West Indian species.

In the garden near by on this same evening I heard high-pitched, intermittent chirping notes reminding me somewhat of our common black field crickets of the States, *Gryllus assimilis* Burmeister. I traced these notes to the inside concrete walls of a large, empty, unused lily pond, and captured several males here. These proved to be odd little crickets of the genus *Amphiacusta*. The species cannot at present be definitely named, and these specimens may be new to entomological science. The crickets of this genus must be much more extensively collected and studied throughout the West Indies before they can be identified or named with any certainty, according to Dr. Ashley B. Gurney.

A dainty tree cricket, a species of *Oecanthus*, was captured in some weeds near the American Embassy one December night. As soon as darkness came on its high-pitched, clear, tinkling chirp was always to be heard. These crickets were not localized in colonies but advertised their presence only as occasional "singers" here and there. When the evening temperatures were high, around 75°–79°F., the cricket chirped with a clear, incisive tonality, but always with a very leisurely delivery. If the temperature fell to near 65°–68°, its chirps became more prolonged and uncertain, with a more pronounced tremulous character. It was interesting to note that even though the mean temperatures around Ciudad Trujillo are always high, around 79°–80°F., with the average minima around 70°–71°F., an especially cool evening with temperatures around 65° was relatively cold to these crickets as it was to human beings long adjusted to these temperature levels.

TABLE 1.—TEMPERATURE AND CHIRPING ATES

Date 1947	Time p.m.	Temperature Outside, F.	Chirps per minute	Humidity
Oct. 19	10:15	72°	18	—
22	9:30	73°	20	88%
24	11:00	72°	18	—
27	11:30	71°	20	—
31	10:00	75°	20	—
Nov. 1	9:40	77°	22	90%
3	9:30	75°	20	Breeze from N.
4	10:00	75°	20	Wind cool N.
8	9:00	73.5°	19	Cool N. wind
9	8:15	71°	18	
9	10:00	70°	silent	
10	9:30	70°	18	
10	10:30	69°	18	
15	9:45	74°	20 (another)	
16	10:45	66° (cool, dry)	16	Very cool, first night for sheet on bed all night.
24	10:30	70°	18	
25	10:30	68°	silent	
Dec. 8	10:40	71°	16	

66°	68°	69°	70°	71°	72°	73°–73.5°	74°	75°	77°
16	silent	18	silent	20	18	20	20	20	22
			18	18	18	19		20	
			18	16				20	

Table 1 presents the observed rates of chirps per minute in relation to different temperature of an *Oecanthus niveus* identified as such by Dr. A. B. Gurney, until further studies could be made.

It is interesting to note that our snowy tree crickets—*Oecanthus niveus*, based on the observations of A. E. Dolbear ("The Cricket as a Thermometer." Amer. Nat. **31:** 790–791, 1897), chirp at a much faster rate than this Dominican species resembling *O. niveus* as determined by the usual morphological characters. As a matter

of fact, our northern *Oecanthus niveus* at a temperature of 70°F. chirped at a rate of 120 times per minute, and even at 60° the rate was 80 times per minute. On the basis of their chirping there is some question whether the West Indian crickets are *Oecanthus niveus*, although this species may also occur here. If so its temperature relations in this tropical climate have undergone a most remarkable change, with a drop of chirping rate of 120 at 70°F. to complete indisposition to chirp at this temperature, or at least to deliver not more than 18 chirps per minute. Even at 77° the highest temperatures of the chirping rates observed in the Dominican Republic, the chirps were only 22 times per minute.

It is at once obvious that the formula $T = 50 + \frac{100 - 40}{4}$ devised by Dolbear for our race of *Oecanthus niveus* will not apply at all to this tropical species. As derived from this formula, if our crickets were chirping at the rate of 100 times per minute, the air temperature should be $50 + \frac{100 - 40}{4} = 65$°F. If the tropical cricket observed in the Dominican Republic is *Oecanthus niveus*, its physiology has undergone a remarkable change with respect to its temperature sensitivity. On the basis of its stridulations this *Oecanthus* may prove to be an entirely different species rather than a greatly modified tropical race of the common snowy tree cricket *Oecanthus niveus*. Dr. A. B. Gurney is at present engaged in a critical study of this species.

MEMBER HONORS

FRANK W. REINHART, chief of the Plastics Section at the National Bureau of Standards, has been awarded the Department of Commerce Silver Medal for Meritorious Service. The award recognized his "major contributions to the science and technology of plastics, and for highly distinguished authorship." Mr. Reinhart, a nationally known authority in the field of plastics, directs the Bureau's diverse research, development, and testing program on plastics, plastic coatings, and adhesives. Among the recent developments of this program are plastic springs which have a higher strength-to-weight than most metal springs, improved transparent eyeshields for the military, and a shatter and craze resistant plastic for use in combat aircraft.

ALAN T. WATERMAN, director of the National Science Foundation, has received the first annual Captain Robert Dexter Conrad award of the Office of Naval Research. The award has been established to recognize outstanding technical and scientific achievements in research and development for the Navy. It is named for Captain Conrad, who, as first head of the Planning Division of ONR, was the primary architect of the Navy's basic research program. The citation, signed by the Secretary of the Navy, reads as follows: "For your outstanding contribution to the organization and long-range scientific objectives of scientific research administration in the Navy. For your vision and leadership in the successful establishment of new concepts and programs in Naval Science. For your personal and exemplary dedication to the building of a solid foundation for the role of the Office of Naval Research in the modern Navy, thereby creating a permanent benefit to the National Defense."

RAY P. TEELE has been elected an Affiliate Member of the Institute of Traffic Engineers, being the only person so honored during 1957. "An affiliate, at the time of admission, shall be a person who, by scientific achievement or practical experience, has attained a position in his special field qualifying him to cooperate with traffic engineers in the advancement of engineering knowledge and practice."

JOSEPH KAPLAN has been elected to membership in the National Academy of Sciences.

HERPETOLOGY.—*A new subspecies of the teiid lizard* Cnemidophorus sexlineatus (*Linnaeus*) *from eastern United States.* RICHARD L. HOFFMAN, Blacksburg, Va.

(Received March 25, 1957)

Thirteen years ago, in 1944, I published a short note concerning the occurrence of *Cnemidophorus sexlineatus* in western Virginia, mentioning that the parietal plates of the specimens examined were divided into several smaller scales. Somewhat later I studied series of racerunners from various places along the Atlantic Coast, and observed a geographic trend in number of parietals, increasing from south to north and reaching a culmination in Maryland and Virginia, whence came specimens having as many as 11 scales in the parietal group. These findings appeared in 1950, in a brief paper which sought to minimize the significance of this variation by endeavoring to explain it in terms of an uninterrupted geographic gradient.

The presentation of my data was made upon a purely latitudinal basis, and involved only the average parietal counts grouped according to the states from which material had been seen. Such an interpretation made no allowance for the evaluation of local populations or any correlation of variability with physiography, and was subsequently challenged (*in litt.*) by Hobart Smith and M. B. Mittleman. I have accordingly adopted a somewhat different arrangement of the data, from which it appears, as suggested by my two colleagues, that a taxonomically recognizable population of the racerunner occurs in Virginia and Maryland, and may be distinguished from the bulk of the *sexlineatus* population by two characters capable of expression in quantative terms.

The character of the parietals, although of unquestionable value, is difficult to treat with precision. In many cases it is almost impossible to say whether a scale is part of the original parietal or merely one of the normal small adjacent plates, and probably no two persons would make the counts in exactly the same way. There is, however, a fortunate correlation in the number of femoral pores, a feature which lends itself well to objective presentation. Reduction in the number of pores is coincident with the fission of the parietals to the extent of being quite useful for diagnostic purposes.

For the present study I have examined a total of 200 specimens from all parts of the range of the species. An effort was made to utilize all of the readily available material from Virginia and Maryland, with several large series from other areas along the Atlantic coast and representative samples of variable size from midwestern localities. The majority of the specimens seen are in the collection of the U. S. National Museum (USNM) and were made available through the characteristic kindness of Dr. Doris M. Cochran. I am further grateful to M. Graham Netting for the opportunity of studying material in the Carnegie Museum (CM); to Dr. Albert Schwartz for the loan of the racerunners of the Charleston Museum (CHM); to James A. Fowler for access to specimens in his private collection (JAF); and to John B. Funderberg for providing a valuable series of specimens from eastern North Carolina.

The population inhabiting central North Carolina, Virginia, and southern Maryland may be recognized, with reference to the reduced femoral pore series, by the name—

Cnemidophorus sexlineatus oligoporus, n. subsp.

Type specimens.—Holotype, USNM. no. 135232, adult male, collected at Griffith, 6 miles east of Clifton Forge, Alleghany County, Va., on May 30, 1953. Allotype, USNM no. 135233, adult female, with same data. Paratypes are indicated in the list of specimens examined.

Diagnosis.—A race of *Cnemidophorus sexlineatus* characterized by a tendency of the parietal plates to divide into a number of small scales, usually 5 or more, and by a corresponding reduction in number of femoral pores, 30 or less in 85 percent of 50 specimens referred to this subspecies on the basis of parietal count and/or geographic provenance, as opposed to 31 or more in 81 percent of 78 specimens of *sexlineatus*.

Range.—From the vicinity of Baltimore, Md.,

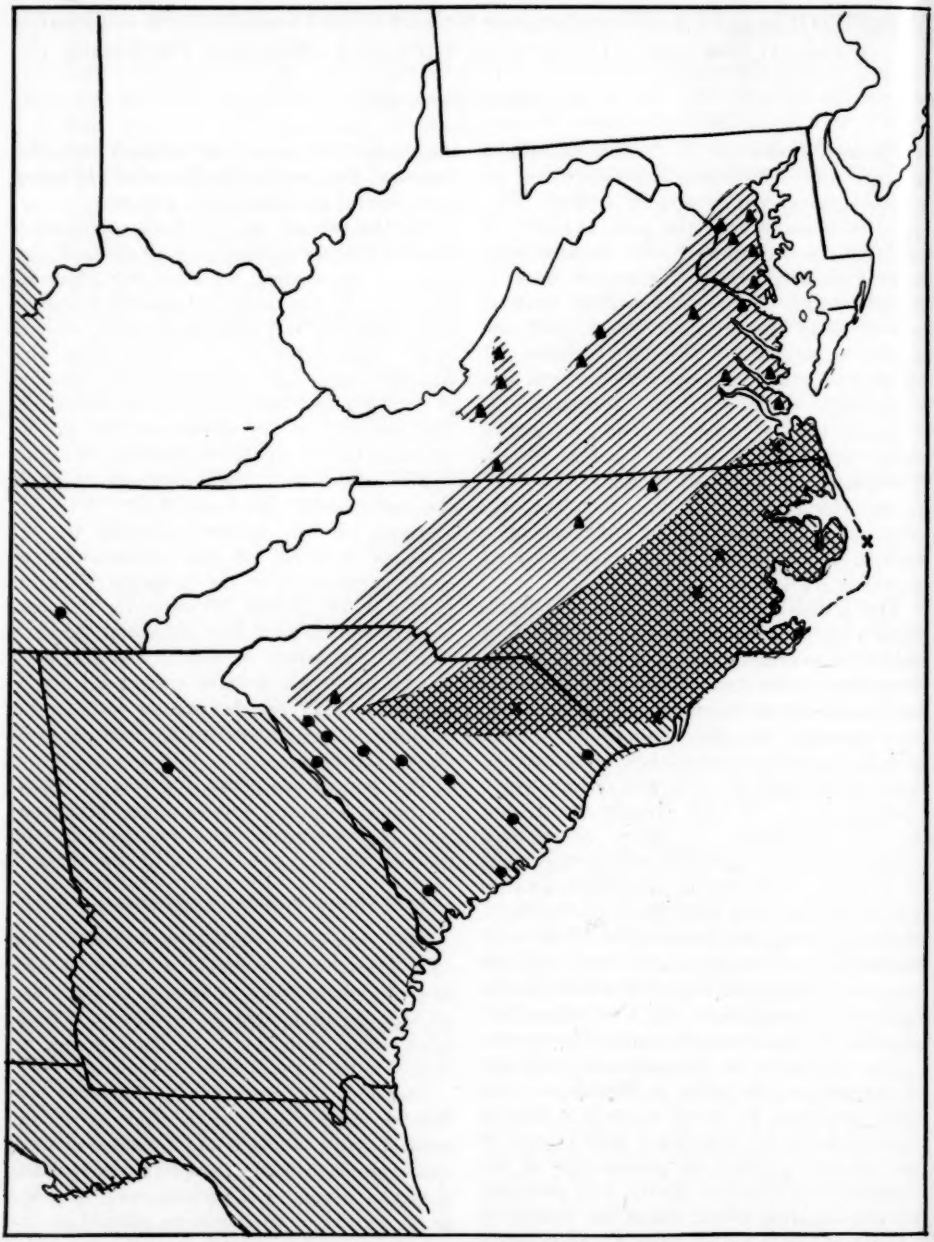

FIG. 1.—Distribution of the subspecies of *Cnemidophorus sexlineatus* in southeastern United States; known or suspected range shown by diagonal shading; symbols representing localities from which specimens were studied. *C. s. sexlineatus* indicated by solid spots and left-to-right shading; *C. s. oligoporus* by solid triangles and right-to-left shading; intermediate samples by X symbols in the cross-hatched area.

south to extreme southeastern Virginia, thence southwest in the Piedmont to Laurens County, S. C. Intergradation with *C. s. sexlineatus* takes place throughout most of the Coastal Plain in North Carolina and along the Fall Line in South Carolina. In Virginia, *C. s. oligoporus* penetrates into the Ridge and Valley Province along the valleys of the James and Roanoke Rivers.

Intergradation.—The status of certain samples has been determined, somewhat empirically, by the following principle: considering the interval between 30 and 31 femoral pores as the break which gives the best separation of specimens on the basis of their geographic provenance, any series of five or more individuals in which the percentage of segregation was more nearly equal than the ratio 70:30 has been regarded as representing an intergrade population. Such data, fitted to a map, provide a fairly accurate delineation of the distribution of this variable. Table 1 presents selected instances of different populations sampled. When single specimens, or small series only, were available, they were determined on the basis of pores, parietal count, place of origin, or a combination of all three.

TABLE 1.—PERCENTAGE SEPARATION OF SPECIMENS FROM VARIOUS LOCALITIES ON THE BASIS OF 30 OR LESS *vs.* 31 OR MORE FEMORAL PORES

Locality and number of specimens	Percentage separation
Southern Maryland (18)	72
Caroline County, Va. (4)	75
Western Virginia (8)	100
Central Virginia (4)	100
New Kent County, Va. (14)	92
Eastern North Carolina (26)	59
Piedmont South Carolina (5)	80
Eastern South Carolina (14)	72
Gwinnett County, Ga. (4)	75
Brevard County, Fla. (10)	90
Florida Keys (10)	80
Central Mississippi (8)	88
Central Tennessee (7)	72
Missouri (7)	86

It is important to observe that there is no evidently consistent continuation of either increase or decrease of femoral pore count in either direction away from the area of intergradation, resulting in a fairly abrupt break between the two subspecies. *C. s. oligoporus* is apparently a product of terminal raciation, and occupies a rather small area in comparison to the total range of the species.

The actual extent of the intermediate population is probably not much different from that as presently known and mapped, although much can yet be done in the way of refinement by analysis of local series from the central parts of North and South Carolina. Of particular value would be a study of the racerunners of western South Carolina and adjacent northwest Georgia, to substantiate or discredit my somewhat tentative allocation of three specimens from Laurens County, South Carolina, to *oligoporus*. Numerous small series from counties on and adjacent to the Fall Line in South Carolina appear to be *C. s. sexlineatus*, with a tendency toward intergrades with *oligoporus*. A small series from northern Georgia (Gwinnett County) is typical of *sexlineatus* in every respect.

The racerunners in the vicinity of Charleston, S. C., which may be considered topotypical *sexlineatus*, appear to be at the edge of the intergrade area, and somewhat affected by a reduction in pore counts. Thus, of 14 specimens from Charleston and adjoining counties, 4 (28 percent) have less than 31 pores and only 10 (72 percent) are referable to *sexlineatus* as here diagnosed. However, the frequency distribution of the available data is skewed sufficiently to the high side to indicate that additional counts would probably create a higher percentage of separation than is now apparent. At the same time, there are enough lower figures from the Charleston region to justify relegation of Merrem's name *fallax* (based on a specimen with 30 pores) to the synonymy of *sexlineatus*.

SPECIMENS EXAMINED

Cnemidophorus sexlineatus oligoporus (63):

MARYLAND. Ann Arundel County: Priest's Bridge, USNM 1; Davidsonville, USNM 1. Calvert County: Cove Point, JAF 4; Chesapeake Beach USNM 2; locality not known, USNM 1. Prince Georges County: Beltsville, USNM 2. St. Marys County: Point Lookout, USNM 6; Piney Point, USNM 2.

DISTRICT OF COLUMBIA: Terra Cotta, USNM 2, JAF 1.

VIRGINIA. Albemarle County: Charlottesville, USNM 3. Alleghany County: Clifton Forge and vicinity, USNM 6 (*paratypes*); Covington, USNM 1 (*paratype*). Botetourt County: Eagle Rock, USNM 1 (*paratype*). Caroline County: Chilesburg, USNM 4. Elizabeth City County: Hampton, USNM 1. Gloucester County: Gloucester Point, USNM 1. Henry County: Spencer, CM 2. Nelson County: Midway Mills, CM 1 (*paratype*). New Kent County: Lanexa, CM 13. Roanoke County:

Roanoke, USNM 1. Westmoreland County: near Hague, USNM 1.

NORTH CAROLINA. Durham County: Durham, USNM 3. Warren County: USNM 1.

SOUTH CAROLINA. Laurens County, USNM 3. Intergrades, *oligoporus* × *sexlineatus* (35):

VIRGINIA. Nansemond County: Suffolk, USNM 1.

NORTH CAROLINA: Brunswick Co.: 5 miles north of Southport, USNM 2. Dare County: Hatteras Island, USNM 3. Lenoir County: Kinston, USNM 17. Pitt County: Greenville, USNM 11.

SOUTH CAROLINA. Darlington County: Darlington, CHM 2.

Specimens regarded as typical of *C. s. sexlineatus* have been examined from the following counties in South Carolina: Barnwell, Berkeley, Calhoun, Charleston, Greenwood, Horry, Jasper, Kershaw, Lexington, McCormick, Saluda, and Sumter, with a total of 25 specimens.

To determine whether the characters of *oligoporus* recur at other parts of the species' range, samples were checked as indicated from the following States: Georgia (4), Florida (27), Mississippi (12), Tennessee (3); Louisiana (5), Kentucky (2), Missouri (8), Kansas (10), Nebraska (2), and Wisconsin (2). In the majority of these specimens there is little or no overlap in parietal or femoral pore counts upon those diagnostic of the northeastern subspecies. However, one other geographically variable character was discovered, the degree of separation of the 3rd supraocular from the adjacent frontoparietal by a row of small intercalary scales. In *C. s. oligoporus*, there are normally two or three such scales between the 3rd supraocular and the frontoparietal, so that those two plates are nearly or entirely separated from each other. In the Midwest, however, they are either completely in contact, or separated only for a very short distance by a single intercalary scale. Unfortunately, the distribution of this interesting character does not coincide with that of the parietal and pore formulas, as it was found that Floridian racerunners were identical with those from Maryland in this respect, and presumably the transition into the western form takes place in Georgia or Alabama. It is, nonetheless, indicative of the various adaptive necessities imposed upon the species during its occupancy of the damper, forested habitat of the Atlantic Coastal region. One is tempted to speculate that the reduction of the femoral pore series reflects slightly shorter legs, perhaps influenced by residence in semi-wooded areas where open ground was quite limited and the necessity for long sprints to shelter less frequent or imperative.

In western Virginia, *oligoporus* is not uncommon in its favorite habitats: railroad embankments, sandy river floodplains, and open shale barrens. These three conditions are combined at the type locality, and a dozen or more lizards can easily be seen during a short walk along the railway. The structural similarity of the montane population to that of lowland Virginia and Maryland confirms my earlier surmise that its members are migrants, rather than relicts. The valleys of the James and Roanoke Rivers offer fairly level avenues of access into the Alleghanies, and the extensive shale barrens of central western Virginia provide abundant habitat for lizards with a preference for open, semiarid areas.

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The annihilation of matter is unthinkable for the same reason that the creation of matter is unthinkable, the reason namely that nothing cannot be an object of thought.—H. SPENCER.

ZOOLOGY.—Teredo (Nototeredo) nambudalaiensis, *a new shipworm from the Madras coast of India.*[1]

N. BALAKRISHNAN NAIR and O. N. GURUMANI, Alagappa College, South India. (Communicated by C. H. Page.)

(Received February 19, 1957)

While engaged in a study of the teredine fauna of the South Indian coast, 19 species of shipworms belonging to the genera *Teredo* and *Bankia* were collected, identified, and described (*1–4*). Of these, 13 were found to be new to science. Roonwal (*5*) recorded the occurrence of the genus *Bactronophorus* from the Sunderbans in the 24 Pargana Districts in Bengal.

This communication deals with one more new shipworm, *Teredo* (*Nototeredo*) *nambudalaiensis*, of which several shells and pallets were collected from a huge log of wood (timber undetermined) washed ashore at Nambudalai (Ramnad District), East Coast, during the monsoon times in January 1956.

Measurements.—Shell length 6.5 mm, shell height 7 mm, pallet length 12 mm, stalk 6 mm, blade 6 mm, diameter of the blade 2 mm.

Characters.—Shell of moderate size. The anterior lobe, anterior median lobe, and a part of the middle median lobe with an olive-green hue; the rest of the shell white. The anterior lobe with a fairly deep sinus at its anterior margin covered with a thin callus reflected over the exterior. The rest of the anterior part is marked by fairly strong riblike dental ridges numbering not less than 66. These ridges are more closely approximated at the anterior callus than at their junction with the median part where the spaces that separate them are more than twice the width of the dental ridges. The dental ridges are slightly wider at the umbone than at the ventral margins. These ridges bear numerous minute, closely spaced denticles on their outer dorsal margin, which give them a serrated appearance. The angle formed at the junction of the anterior part with the anterior median part at its ventral margin is obtuse. The anterior and posterior portions of the median lobe are convex, while the middle median portion is slightly concave. The anterior median is narrower than the posterior median and marked by closely crowded dental ridges numbering not less than 82. These ridges bear strong closely crowded tubercles and the ridges are separated by deeply impressed lines. In the type specimen many of the tubercles toward the umbonal side are worn out. The middle and posterior median parts are marked by the enfeebled extensions of the dental ridges of the anterior area. The posterior portion forms a moderately large auricle marked by incremental lines.

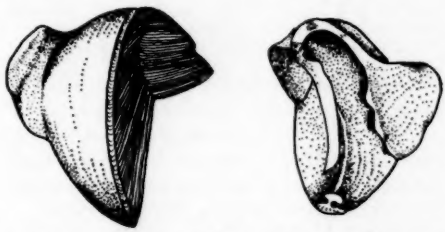

FIG. 1.—Shell of *Teredo* (*Nototeredo*) *nambudalaiensis*, n. sp.: *Left*, outer view; *right*, inner view.

The interior is pearly white. The umbones form a strong knob from the inner under side of which the sickle shaped and fairly broad blade curves across, about two-thirds the inside of the shell toward the ventral knob, which is quite strong in this form. The junction of the anterior lobe with the median is in the form of a threadlike ridge, and the posterior portion extends over the median on the inside as a narrow shelf.

The pallet is elongated and cricket-bat shaped. It is not cupped distally. The blade is flat and its external surface is slightly convex showing longitudinal groove distally for about half the length of the blade. The stalk insensibly merges with the blade and extends as a tumid ridge to the tip of the blade on its inner aspect.

Remarks.—Of the three genera *Teredo*, *Bankia*, and *Bactronophorus*, which constitute the family Teredinidae, the present form belongs to the genus *Teredo* Linnaeus (1758), since the pallets

[1] Contribution from the Research Section, Zoology Department, Alagappa College, Karaikudi, South India.

are paddle shaped. The genus includes about 12 subgenera. The form before us comes under the subgenus *Nototeredo* by virtue of the following features: The posterior part of the shell is so attached to the posterior median part as to form a decided shelf projecting inward. Further, the pallet is elongated and flattened, with no cupping at the extremities, appearing somewhat like a cricket bat. This subgenus was established in 1923 by Bartsch (*6*) on the basis of the form *Teredo* (*Nototeredo*) *edax* Hedley.

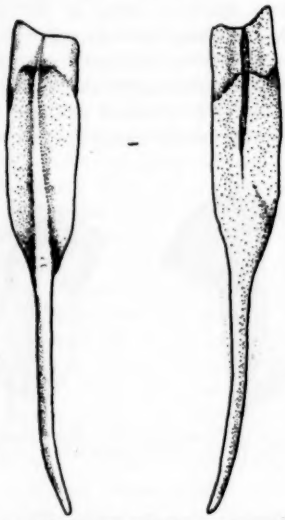

FIG. 2.—Pallet of *Teredo* (*Nototeredo*) *nambudalaiensis*, n. sp.: *Left*, inner view; *right*, outer view.

A comparative study of the characters of the two species included under this subgenus suggests that the present form does not belong to either of them. However, it shows some resemblance to *Teredo* (*Nototeredo*) *edax* Hedley in having an elongated cricket-bat shaped pallet which is not cupped distally, but differs from it in the nature of the stalk, which is almost as long as the blade. Further, *Teredo* (*Nototeredo*) *edax* is reported as having "curious growth corregations covering most of the outer surface and the tips of the inner surface" (*7*). Moreover, a detailed study of both the pallet and the shell shows that the form before us is one hitherto undescribed and hence to be treated as a species new to science, **Teredo (Nototeredo) nambudalaiensis,** defined as follows:

Teredo with a distinctly paddle-shaped pallet with an elongated blade, not cupped distally, which is a little concave on its inner surface and convex on its outer aspect and marked by a longitudinal gooove extending for less than half of the blade at its distal aspect, with a stalk which is almost the legth of the blade, cylindrical and tapering, merging insensibly with matrix of the blade and extending to the tip of the latter as a tumid ridge on the inner surface.

A shell whose height is slightly more than its length, with a moderately well developed auricle, which forms a narrow shelf projecting into the median portions and having a sickle shaped and broad blade extending for about two-thirds the distance from the umbone to the ventral knob. The type will be deposited in the Zoological Survey of India, Calcutta.

Acknowledgment.—Thanks are due to T. Sri Ganesh for the illustrations.

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In framing hypotheses we must see that they agree with facts; in other respects they may be as inconceivable (not self-contradictory) as any fairy tale.
—M. M. P. MUIR.

ZOOLOGY.—*North American genera of the family Orbiniidae (Annelida: Polychaeta), with descriptions of new species.*[1]

MARIAN H. PETTIBONE, University of New Hampshire. (Communicated by Fenner A. Chace, Jr.)

(Received March 22, 1957)

The study of several series of specimens belonging to the Orbiniidae has indicated the need to modify the definitions of some of the genera of this family. Since the monographic work of Eisig (1914) on the systematics and morphology of the Ariciidae (=Orbiniidae), the family name and general systematics used in that revision have been followed by most workers. Some genera have been added to the family, however. The following revision includes those genera that were represented by material available for study in the United States National Museum. Three new species of orbiniids are described from the east coast of North America and one from the west coast. A new subgenus is proposed and new names are given for two species. The types are deposited in the United States National Museum.

FAMILY ORBINIIDAE

Type genus: *Orbinia* Quatrefages, 1866 = *Aricia* Savigny, 1822, preoccupied.

Prostomium oval, truncate or conical, without appendages. First 1 or 2 segments achaetous, without appendages (these segments may be biannulate, thus buccal segment may appear 1- to 4-ringed). Parapodia biramous, supported by acicula. Body divided into two regions. Anterior thoracic region bearing dorsolateral notopodia with crenulate capillary notosetae; more or less developed postsetal notopodial lobes (dorsal cirri of Eisig); lateral neuropodia with crenulate capillary setae, crotchets, pseudocrotchets, transitional setae (subuluncini), or spines; and more or less developed postsetal lobes with or without podal papillae. Abdominal region with parapodia shifted dorsally, noto- and neuropodial lobes elongate, ligulate, both noto- and neurosetae crenulate capillaries; notopodia sometimes with additional shorter forked setae with inner part of fork somewhat frayed (perhaps these are broken crenulate capillaries; at least they do not appear to be as regular in structure as in the polychaete families where true forked setae are found). Paired simple (rarely branched) ligulate ciliated branchiae dorsal to notopodia on all segments of body except some anterior ones. Anal cirri 2 or 4. Proboscis an eversible, unarmed, soft sac, slightly lobulate or voluminous, branched. Burrow in sand or mud. Bottom-deposit feeders.

Genus **Orbinia** Quatrefages, 1866

Aricia Savigny, 1822, preocc.; type (by monotypy): *A. sertulata* Savigny, 1822.
Orbinia Quatrefages, 1866; type (by original designation): *O. sertulata* (Savigny) = *Aricia cuvierii* Audouin and Edwards, 1833.

Diagnosis.—Prostomium conical. Achaetous buccal segment 1-ringed. Postsetal neuropodial lobes of thoracic segments fimbriated—with vertical row of 4–7 or more papillae; sometimes papillae continued subpodally on some segments.

Remarks.—In the original description by Savigny of *Aricia sertulata* from La Rochelle, France, the anterior end was described as having two pairs of very small antennae on the sides of the small conical prostomium and eyes slightly distinct. When in 1883 Audouin and Edwards added two more species of *Aricia*, *A. cuvierii* and *A. latreillii*, and established the family Ariciidae, the prostomium was described as being without antennae and without eyes. As more species have been found and added to the family, none with prostomial antennae have been described. It has generally been considered that the type specimen of Savigny must have been defective. In 1866 Quatrefages proposed the generic name *Orbinia* for Savigny's species which he credited with having 5 antennae (4 antennae in Savigny's description); he used *Aricia* in the sense of Audouin and Edwards for species without antennae, as *A. cuvierii* and *A. latreillii*. According to the present rules of nomenclature, he should have done the opposite. Subsequent workers have used *Aricia* in the sense of Audouin and Edwards. Except for the differences in the prostomium, there is remarkable agreement in the descriptions of *A. sertulata* and *A. cuvierii*; both came origi-

[1] This study was aided by a grant from the National Science Foundation (NSF-G 2012).

nally from the western coast of France. Eisig, in his monograph, referred *A. sertulata* questionably to *A. cuvierii*. Since there is no way of examining Savigny's type, it seems best to assume that the type specimen was defective anteriorly, to maintain *sertulata* as the type of both *Aricia* and *Orbinia* and to synonymize *A. cuvierii* with it. The other choice would be to assign *Aricia* and *Orbinia* to the list of indeterminate genera and give a new name to the genus containing *cuvierii* and similar species. Since the description of *sertulata* is adequate in other respects, it would seem best to retain it.

Subgenus **Orbinia**

Diagnosis.—Without spikelike or lanceolate spines on any posterior thoracic neuropodia.

Subgenus **Phylo** Kinberg, 1866

Type (by monotypy): *P. felix* Kinberg, 1866; see Hartman, 1949, p. 251.

Diagnosis.—With large spikelike or lanceolate spines on some posterior thoracic neuropodia.

Genus **Scoloplos** Blainville, 1828

Type (by monotypy): *Scoloplos armiger* (O. F. Müller, 1776).

Diagnosis.—Prostomium conical. Achaetous buccal segment 1-ringed. Thoracic neuropodia with postsetal lobes not fimbriated, with 0–3 podal papillae; sometimes with subpodal or ventral papillae on some segments.

Subgenus **Scoloplos**

Labotas Kinberg, 1866; type (by monotypy): *L. novae-hollandiae* Kinberg, 1866.
Branchethus Chamberlin, 1919; type (by monotypy): *B. latum* Chamberlin, 1919.
Haploscoloplos Monro, 1933; type (by original designation): *Scoloplos cylindrifer* Ehlers, 1904.

Diagnosis.—Postsetal lobes of thoracic neuropodia with papilla in middle of lobe, with or without 1 or 2 additional papillae in lower part.

Remarks.—The typical subgenus, as here defined, includes species referred to *Haploscoloplos* Monro (1933, p. 261), which was established to include those species which differ from *Scoloplos* in having the thoracic neuropodia provided only with setae ending in capillary tips, without crotchets. In some cases this character is difficult to observe; the crotchets may be easily missed, occurring in some thoracic neuropodia and not in others. Until it can be established how much the abrasive action of certain substrata has to do with the formation of certain types of crotchets from capillaries, the character does not seem to be a good one. *S.* (*S.*) *latus* (Chamberlin, 1919), the type species of *Branchethus* Chamberlin, 1919, p. 357, differs from most other species of *Scoloplos*, which usually have simple branchiae, by having the branchiae with up to 9 branches; this is of specific but not of generic significance. *Branchethus* was referred to *Scoloplos* by Fauvel (1932, p. 167). *Labotas* Kinberg was referred to *Scoloplos* by Augener (1922, p. 40).

Subgenus **Leodamus** Kinberg, 1866

Type (by monotypy): *L. verax* Kinberg, 1866; see Hartman, 1949, p. 104.

Diagnosis.—Thoracic neuropodia with postsetal lobes low, rounded, without papillae.

Remarks.—*S.* (*L.*) *johnsoni* (Moore, 1909, p. 260), which was described under *Aricia*, referred to *Scoloplos* by Eisig (1914, p. 403) and to *Orbinia* by Hartman (1944, p. 258), does not have the thoracic neuropodia fimbriated as in *Orbinia*, although it has subpodal ventral or stomach papillae more commonly found in species of *Orbinia*.

Genus **Naineris** Blainville, 1828

Naidonereis Malmgren, 1867.
Nainereis Mesnil and Caullery, 1898.

Type (by monotypy): *Naineris quadricuspida* (Fabricius, 1780).

Diagnosis.—Prostomium oval or truncate, loaf-shaped. Thoracic neuropodia with 0–3 postsetal papillae.

Remarks.—*Theodisca* Fr. Müller, 1858, has been referred to *Naineris* by Eisig (1914, p. 498); the description and figures of the type species, *T. aurantiaca* Fr. Müller, seem insufficient to determine just where among the orbiniids it belongs.

Subgenus **Naineris**

Diagnosis.—Thoracic neuropodia with single postsetal papilla in middle of lobe, with or without 1–2 additional papillae in lower part. Achaetous buccal segment 1- to 4-ringed.

Polynaineris, n. subgen.

Anthostoma Schmarda, 1861, preocc.; type: *A. ramosum* Schmarda, 1861 (see below), = *Naineris laevigata* (Grube).
Lacydes Kinberg, 1866, preocc.; type (by monotypy): *L. havaicus* Kinberg, 1866, = *Naineris laevigata* (Grube).

Type: *Naineris laevigata* (Grube, 1855).

Diagnosis.—Thoracic neuropodia without postsetal papilla in middle of lobe, with postsetal lobe rounded or diagonally truncate, upper part sometimes elongate, papilla-like. Achaetous buccal segment 1-ringed.

Remarks.—*Anthostoma* Schmarda, 1861, preocc., included *A. hexaphyllum* from Cape of Good Hope and *A. ramosum* from Jamaica. I am selecting the latter species as the type. Both species have been referred to *Naineris laevigata* Grube, 1855); see Eisig, 1914, p. 450. The subgenus *Polynaineris* includes most of the species that have been referred to *Naineris*.

Orbinia (Orbinia) swani, n. sp.

Fig. 1, a–f

The species is based on a single specimen, incomplete posteriorly (U.S.N.M. no. 28296), collected at York Beach, Maine, by Emery Swan and Nathan Riser, July 12, 1953. It is named for Dr. Swan, one of the collectors.

Description.—Length 41 mm for 58 setigers, greatest width 2 mm. Body widest in thoracic

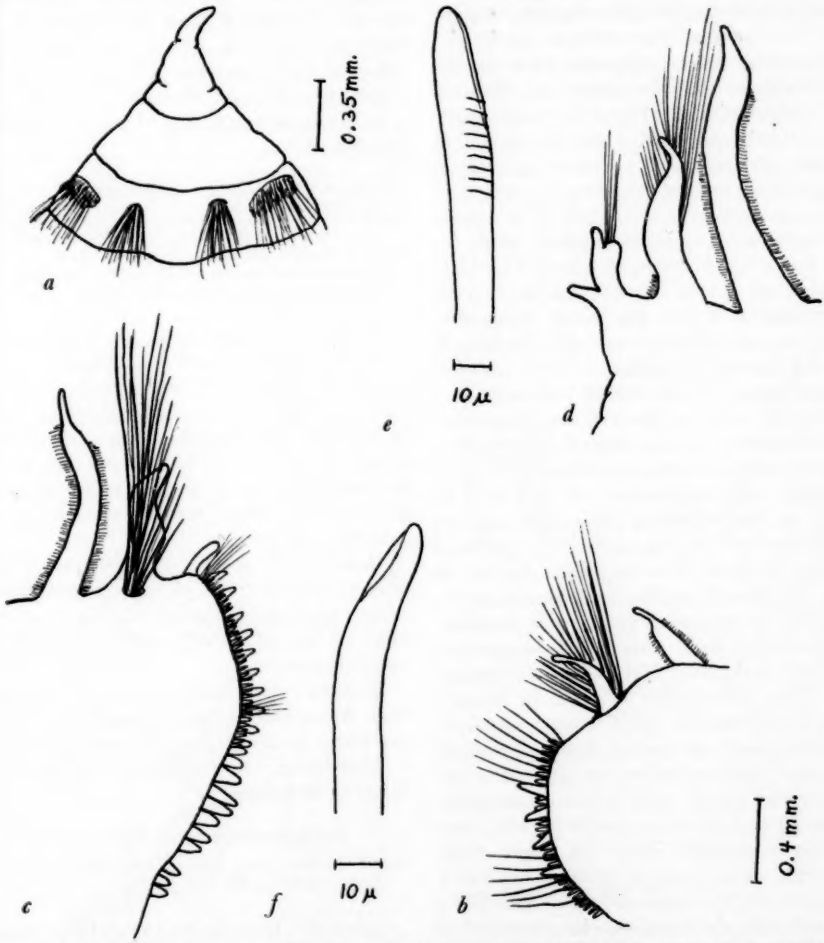

FIG. 1.—*Orbinia swani*, n. sp.: *a*, Dorsal view anterior end; *b*, left thoracic setiger 5, posterior view; *c*, left thoracic setiger 26, anterior view; *d*, left setiger 55 (abdominal 24), posterior view; *e*, thoracic neuropodial crotchet from setiger 5; *f*, same, from setiger 26. (All parapodia drawn to same scale.)

region, tapering abruptly anteriorly and gradually posteriorly. Thoracic region flattened dorsoventrally, abdominal region strongly convex ventrally, flattened dorsally. Large intersegmental middorsal glandular areas beginning between setigers 6 and 7. Prostomium (Fig. 1,a) acutely conical, somewhat wrinkled, longer than wide. Achaetous buccal segment obscurely biannulate, narrower and slightly longer than the following; large mouth with lateral lips formed by buccal segment; lower lip formed by ventral part of first and part of second setigers. Proboscis not extended. Branchiae beginning on setiger 5, short anteriorly, becoming elongate, ligulate, densely ciliated up to near the narrower distal tip; branchiae longer than parapodial lobes on abdominal region. Thoracic setigers 31. Thoracic notopodia dorsolateral (Fig. 1,b,c) with digitiform postsetal lobe and radiating bundle of crenulate capillary setae. Thoracic neuropodia lateral, forming an oval transverse cushion, with several transverse rows of crotchets (4 or 5 rows) and 2 groups of crenulate capillary setae, an upper and a lower group; crotchets (Fig. 1,e,f) golden-yellow, gently curved, smooth or with faint spinous rows, with tips bluntly rounded or conical; neuropodial postsetal lobes fimbriated, with 3–6 postsetal papillae in more anterior segments (none on first setiger), becoming more numerous in more posterior thoracic segments (up to 18 crowded papillae where best developed). Subpodal ventral papillae on setigers 19–40 (last 13 thoracic, first 9 abdominal), few at first (1 on setigers 19, 20), becoming more numerous and forming crowded ventral papillae in continuous line with 18 postsetal neuropodial papillae on setiger 28; ventral papillae decreasing markedly in number on abdominal setiger 4 (6 papillae), then decreasing to 2, then 1 and disappearing after ninth abdominal. Notopodia of abdominal region (Fig. 1,d) similar to those of thoracic region but notosetae more faintly crenulate, sometimes short and forked (broken crenulate capillaries?); without interramal cirri; with interramal ciliated lateral organ at base of notopodia. Abdominal neuropodia unequally bilobed, inner lobe shorter, rounded, outer lobe longer, digitiform, with small bundle of crenulate capillaries. Anterior abdominal segments (some 7 transitional ones) with subpodal lateral papillae corresponding in position to postsetal neuropodial papillae of the thoracic segments, decreasing in number from 7 papillae on first abdominal to single one on eighth and remaining abdominal segments (at least to end of incomplete specimen).

Remarks.—Orbinia swani lacks special lanceolate spines in the posterior thoracic neuropodia and thus differs from the species belonging to the subgenus *Phylo*. It differs from *O. sertulata* (Savigny) and *O. latreillii* (Audouin and Edwards) in lacking interramal cirri on the abdominal segments and from *O. ornata* (Verrill) in having subpodal papillae or ventral cirri on the abdominal segments. *Orbinia swani* (thoracic setigers 31; subpodal ventral papillae on 22 segments) is close to and intermediate between *O. armandi* (McIntosh) from the Atlantic, off the Shetlands (thoracic setigers 19; long, villous subpodal ventral papillae on 6 segments) and *O. bioreti* (Fauvel) from Madagascar (thoracic setigers 34–39; subpodal ventral papillae on about 25 segments).

Scoloplos (Scoloplos) pugettensis, n. name

Scoloplos elongata Johnson, 1901, p. 412, pl. 10, figs. 105–110. Not *S. elongatus* Quatrefages, 1866. *Haploscoloplos elongata* Hartman, 1948, p. 30.—Hartman and Reish, 1950, p. 26.—Berkeley and Berkeley, 1952, p. 97, fig. 200; 1956a, p. 242.

Diagnosis.—Length up to 195 mm, width up to 3 mm, segments up to 300. Thoracic setigers about 20 (19–22). Thoracic neuropodia with conical postsetal papilla and all neurosetae ending in capillary tips. Branchiae beginning on about setiger 16 (15–18). Abdominal segments without interramal cirri or subpodal papillae or ventral cirri but with entire, elongate, sometimes undulate subpodal flanges.

Remarks.—S. pugettensis differs from *S. acmeceps* Chamberlin by having all the thoracic neurosetae ending in capillary tips; in *S. acmeceps*, there are several rows of crotchets in addition to the capillaries.

Material examined.—Numerous specimens from Washington and Puget Sounds, Washington, low water to 12 fathoms, mud, gravelly-sand.

Distribution.—Arctic Alaska to California. Low water to 30 fathoms.

Scoloplos (Scoloplos) dayi, n. name

Orbinia dubia Day, 1955, p. 409, fig. 1, a–d. Not *Scoloplos dubia* Tebble, 1955.

Remarks.—Orbinia dubia Day, 1955 (issued in October) has thoracic neuropodia with only 1–3 podal papillae, thus not fimbriated as in *Orbinia*, although there are stomach papillae as in many

species of *Orbinia*. According to the revision proposed herein, the species should be referred to *Scoloplos*. Unfortunately *Scoloplos dubia* is preoccupied by Tebble (1955, p. 123, issued in August). I have therefore given the name *Scoloplos dayi* to Day's species from South Africa.

Scoloplos (Scoloplos) riseri, n. sp.

Fig. 2, a–d

The species is known from a single specimen, incomplete posteriorly, collected in the Woods Hole region, Massachusetts, August 8, 1950, exact locality unknown (U.S.N.M. no. 28295). It is named for Dr. Nathan Riser.

Description.—Length 25 mm for 100 segments, greatest width 1.5 mm. Body sublinear, tapering rather abruptly anteriorly and gradually posteriorly. Thoracic region flattened dorsoventrally, abdominal region strongly convex ventrally, flattened dorsally. Prostomium (Fig. 2,a) acutely conical, longer than wide, sometimes wrinkled, appearing 2- to 3-ringed, with pair of minute deep-set eyespots laterally near base of prostomium. Achaetous buccal segment narrower and about same length as the following; buccal segment and part of first setiger involved in mouth. Proboscis not extended. Branchiae beginning on setiger 10, short at first, becoming long, ligulate, densely ciliated up to near distal tip. Thoracic setigers 19. Thoracic notopodia (Fig. 2,b) with digitiform postsetal lobe and radiating bundle of crenulate capillaries. Thoracic neuropodia forming an oval cushion-like lobe with several transverse rows of shorter crotchets and posterior row of longer crenulate capillaries; crotchets (Fig. 2,d) straight or slightly curved, with tips blunt to conical, appearing hooded at certain angles, with transverse spinous rows. Short, rounded postsetal neuropodial lobe with single conical papilla on first 11 setigers, 2 or 3 postsetal papillae on rest of thoracic setigers. Abdominal setigers (Fig. 2,c) with notopodial postsetal lobe longer than in

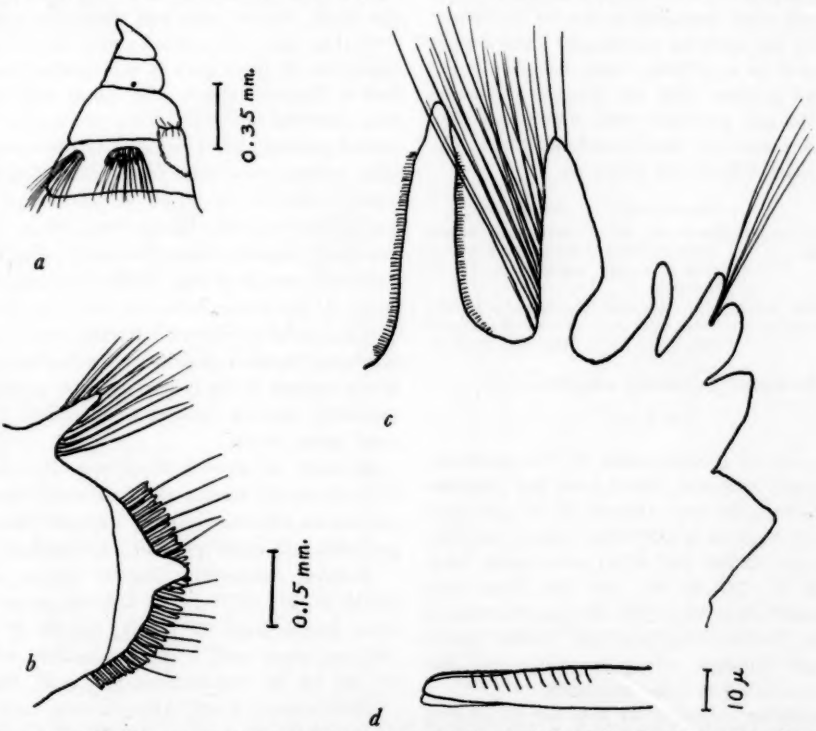

FIG. 2.—*Scoloplos riseri*, n. sp.: *a*, Lateral view anterior end; *b*, right thoracic parapodium from setiger 6, posterior view; *c*, right parapodium from setiger 30 (tenth abdominal), posterior view; *d*, thoracic neuropodial crotchet. (Both parapodia drawn to same scale.)

those of thoracic region, ligulate, with bundle of faintly crenulate capillaries and some shorter forked notosetae (broken crenulate capillaries?). Neuropodia with two subequal, short, digitiform lobes and small bundle of faintly crenulate capillaries. An interramal cirrus on last 2 thoracic setigers and continuing on about 70 abdominal segments. Subpodal papillae on setigers 14–24 (last 6 thoracic, first 5 abdominal): setigers 14–16 with single lateral papilla; setiger 17 with 2 lateral and 2 ventral papillae on each side; setiger 18 with 2 lateral and 4 ventral papillae; setigers 19–21 with 7–9 papillae forming continuous row nearly reaching midventral line; setigers 22–24 with 3 subpodal lateral papillae; 2 wide conical subpodal papillae on rest of abdominal segments (Fig. 2,c), corresponding in position to entire subpodal flange found in some species of *Scoloplos*.

Remarks.—*S. riseri* differs from most of the other species of *Scoloplos* by having subpodal ventral papillae on some anterior segments; these are found more commonly in species of *Orbinia*. However the postsetal neuropodial lobes are not fimbriated as in *Orbinia*, there being only 1–3 postsetal papillae. Also the anterior abdominal segments are provided with interramal cirri. *S. riseri* is close to *S. dayi* from South Africa. The two species differ in the following:

	Scoloplos dayi	*Scoloplos riseri*
Subpodal ventral papillae	Present on setigers 15–32, up to 20 in a row on each side.	Present on setigers 14–24, up to 9 in a row on each side.
Abdominal subpodal region	Entire subpodal flange after setiger 32.	Two subpodal papillae or slashed subpodal flange after setiger 24.

Scoloplos (Scoloplos) schmitti, n. sp.

Fig. 3, a–h

The species is represented by 21 specimens, incomplete posteriorly, taken from four *Albatross* stations from the deep Atlantic off the east coast of North America in 1883–1885. The types (U.S. N.M. nos. 28298 and 3178) were taken from 37° 12′ N., 74° 20′ W., 788 fms., blue mud, *Albatross* Station 2018, 1883. The species is named for Dr. Waldo Schmitt of the United States National Museum, whose encouragement and help have aided so many zoologists.

Description.—Length 20 mm for 50 setigers (none complete), greatest width 2 mm. Body widest in thoracic region, tapering rather abruptly anteriorly and gradually posteriorly. Thoracic region flattened dorsoventrally; abdominal region convex ventrally, flattened dorsally. Prostomium (Fig. 3,a) subtriangular, bluntly conical, about as wide as long. Achaetous buccal segment slightly longer than the following; buccal segment and first setigerous segment involved in mouth (Fig. 3,b). Proboscis only partially extended, appearing as a lobulated sac. Branchiae beginning on setiger 9 (8–10), flattened, triangular, tapering to slender tips, becoming longer in more posterior segments. Thoracic setigers 13–14. First three setigers (Fig. 3,b,c) differ markedly from rest of thoracic setigers; notopodia with small conical postsetal lobe and radiating bundle of long crenulate capillary setae; neuropodia forming oval cushion-like lobe, without postsetal papillae, with 3 kinds of setae: (1) 2 rows of smooth, stout, reddish amber-colored spines with tips straight or curved, pointed and hooded, the hood frayed in various ways (Fig. 3,f,g); (2) anterior row of short crotchets (not as stout as the spines), with tips blunt, frayed hood, and transverse spinous rows (Fig. 3,h); (3) a small group of crenulate capillaries at upper part of neuropodial bundle. Rest of thoracic setigers (Fig. 3,b,d) with digitiform postsetal notopodial lobe; neuropodia with conical postsetal lobe, with several rows of crenulate capillary neurosetae (sometimes a few short hooded crotchets on setiger 4). Abdominal segments (Fig. 3,e) with bilobed neuropodium; inner lobe short, rounded; outer lobe longer, digitiform, with small bundle of long, faintly crenulate capillaries. A low entire subpodal lobe. No ventral cirri, subpodal papillae or interramal cirri. Large middorsal brownish glandular area beginning between setigers 9–10; brown pigment sometimes extending laterally forming characteristic transverse brown bands.

Remarks.—*S. schmitti* differs from other species of *Scoloplos* by having the first three thoracic neuropodia differing markedly from the following, provided with stout spines of a special type.

Material examined.—*Albatross* station 2207, 39° 35′ N., 71° 31′ W., 1,061 fathoms, green mud, 1884; station 2234, 39° 09′ N., 72° 03′ W., 810 fathoms, green mud, 1884; station 2531, 40° 42′ N., 66° 33′ W., 852 fathoms, grey mud, 1885.

Distribution.—North Atlantic, deep water off east coast North America (off Massachusetts to off New York). 788 to 1,061 fathoms.

Naineris (Naineris) berkeleyorum, n. sp.

Fig. 4, a–f

Nainereis quadricuspida? Berkeley and Berkeley, 1956b, p. 544, fig. 5; not Fabricius, 1780.

The type (U.S.N.M. no. 28297) is a complete specimen collected on Smith Island in the Strait of Juan de Fuca, Washington, August 1, 1940. The specimens reported by Mr. and Mrs. Cyril Berkeley (1956) from False Bay, San Juan Island, as doubtfully *N. quadricuspida*, certainly belong to this species which is here named for them.

Description.—Length 180 mm, greatest width 3 mm, segments about 350. Body widest in thoracic region which tapers gradually anteriorly

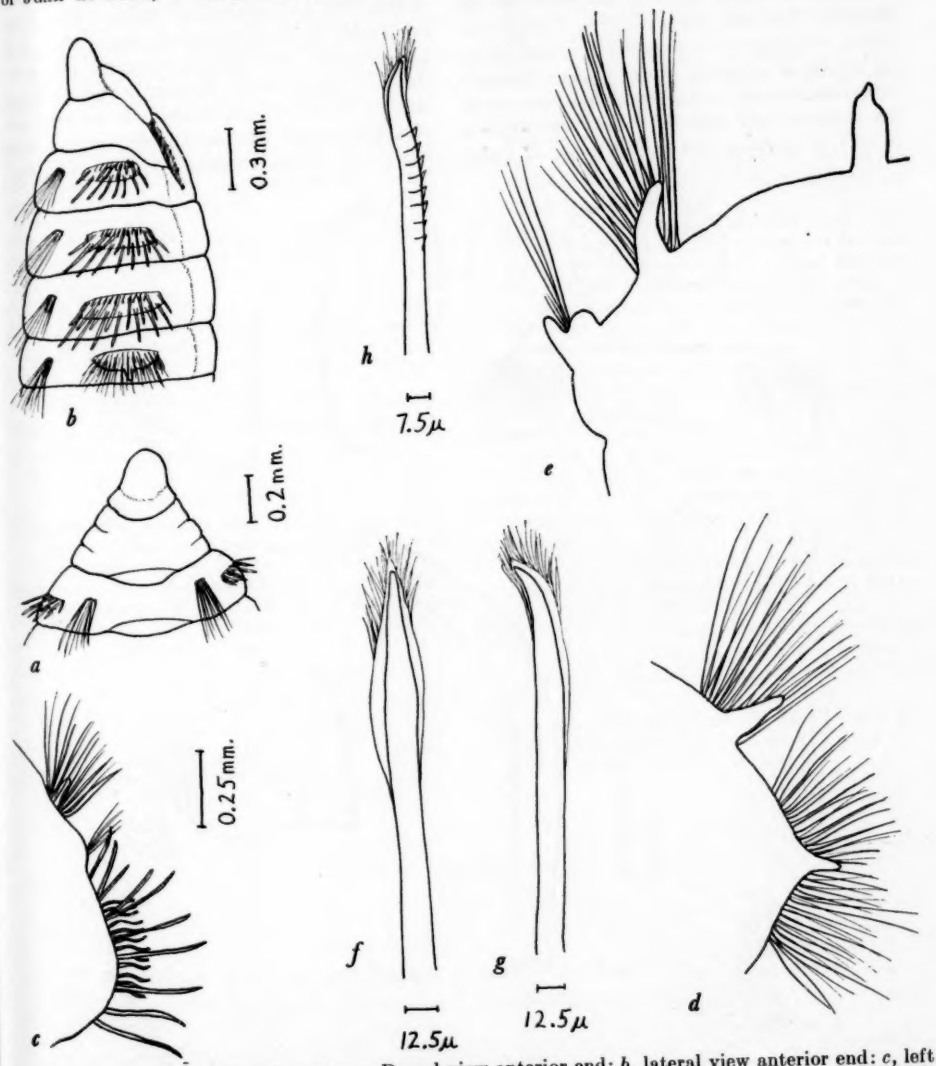

FIG. 3.—*Scoloplos schmitti*, n. sp.: *a*, Dorsal view anterior end; *b*, lateral view anterior end: *c*, left parapodium from setiger 3, anterior view; *d*, right parapodium from setiger 12, posterior view; *e*, left parapodium from setiger 15 (first abdominal), posterior view; *f*, *g*, neuropodial spines from setiger 2; *h*, short crotchet from setiger 2. (All parapodia drawn to same scale.)

and is flattened dorsoventrally; abdominal region long, convex ventrally, flattened dorsally. Prostomium (Fig. 4,a) truncate, loaf-shaped, wider than long. Achaetous buccal segment about same length as the following. Branchiae beginning on setiger 5, short anteriorly, becoming elongate, ligulate, densely ciliated up to near narrower distal tips; branchiae longer than parapodial lobes on abdominal region. Thoracic setigers 26 (26–27, Berkeley). Thoracic notopodia (Fig. 4,b,c) dorsolateral, with digitiform postsetal lobe and radiating bundle of crenulate capillary setae. Thoracic neuropodia lateral, forming oval transverse cushion, with several transverse rows of crotchets (6 or 7 or so rows) and posterior row of longer crenulate capillary setae; crotchets (Fig. 4,e,f) reddish bronzy, straight or curved, with transverse denticled rows, with tip entire or slightly incised (appears hooded at certain angles). No transitional setae (subuluncini). First 6 thoracic setigers with single conical postsetal papilla near middle of lobe (Fig. 4,b); rest of thoracic setigers with additional postsetal papilla near lower part of lobe (Fig. 4,c). Abdominal region with notopodia similar to those of thoracic region (Fig. 4,d), but notosetae more faintly crenulate; also some shorter forked setae (broken crenulate capillaries?). Neuropodium bilobed; inner lobe low, rounded; outer lobe short, digitiform; small bundle of faintly crenulate capillaries; single,

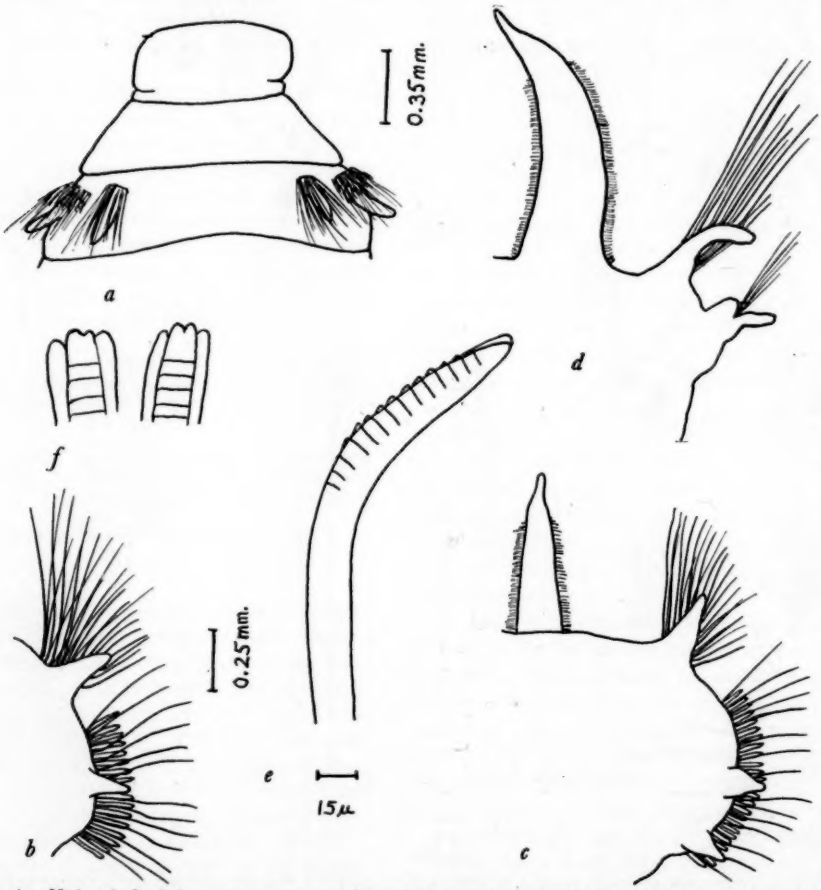

FIG. 4.—*Naineris berkeleyorum*, n. sp.: *a*, Dorsal view anterior end; *b*, right thoracic parapodium from setiger 4, posterior view; *c*, same, from setiger 18; *d*, right parapodium from setiger 40 (abdominal setiger 14), posterior view; *e*, thoracic neuropodial crotchet; *f*, tips of same, frontal view. (All parapodia drawn to same scale.)

slightly projecting amber-colored, curved aciculum with blunt or slightly notched tip. Subpodal papilla on first few abdominal setigers (5 or so) corresponding in position to lower postsetal papilla of thoracic setigers. Posterior end cylindrical, ending in 4-lobed anal segment; lobes dorsal, lateral and ventral, with 4 short slender anal cirri alternating with them. Proboscis partially extended in type, appearing as simple lobulated sac. Color (in alcohol) pale yellowish.

Remarks.—*Naineris berkeleyorum* resembles *N. quadricuspida*. It differs in the following:

	Naineris quadricuspida	*Naineris berkeleyorum*
Prostomium	Globular	Loaf-shaped
Number of thoracic setigers	About 13 (11–17)	26–27
Thoracic postsetal neuropodial lobe	Single median postsetal papilla on all thoracic setigers.	Single median postsetal papilla on first 6 setigers; 2 papillae on rest of thoracic setigers.
Subpodal papilla	None	Single one present on few anterior abdominal setigers (5 or so).

Distribution.—West coast North America (Strait of Juan de Fuca and San Juan Archipelago, Wash.). Low water.

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Definition is the end and epilogue of science. It is not the beginning of our knowing, but only of our teaching.—T. CAMPANELLA (1590).

HABITS OF HORNBILLS

Lady hornbills are trusting wives, and gentlemen hornbills are the most unbelievably faithful husbands.

Hornbills are birds, the size of small turkeys with enormous beaks, usually found in pairs in the forests of East Africa. A comprehensive report on the behavior of these grotesque birds in the Mpanga Research Forest, near Entebbe, Uganda, by Dr. Lawrence Kilham, of Bethesda, Md., has recently been published by the Smithsonian Institution. The account is a classic of bird-watching.

Hornbills are perhaps best known from the curious instinctive behavior of the female. Before laying her annual quota of two eggs she walls herself with mud, collected by the male, into a hole near the top of some high jungle tree. There one of the eggs—apparently seldom both—is hatched and the chick reared. The female continues this voluntary imprisonment for two months or more. There is always a small aperture in the wall. Through this the foraging male passes food to his imprisoned mate, once an hour or less. Food consists mostly of fruits. Sometimes he brings her what apparently are playthings to relieve the monotony of hatching and chick-rearing.

Hornbills mate for life and apparently their conjugal life is a model of high morality for the whole animal kingdom. Walled into the tree-holes, the females obviously are helpless to protect themselves against any infidelity, and, sad to say, there are vampire female hornbills in the jungle whose only thought is to steal some imprisoned lady's spouse. In the case observed by Dr. Kilham, however, the male preserved his virtue to the end.

> By November 8 [he records], the female was walled in, and a more serious attempt at interference was now made by a foreign female. . . . She was following the male and lighted in the next tree when he lighted above his nest hole. On November 23 the same course of events took place, except that the male was less tolerant. He fed his own mate, then drove the intruder away. A week later I saw her fly in close behind the male and light 25 feet from the nest hole. The male gave his mate a piece of bark followed by some fruit, and then bounced from one branch to another toward the foreign female.
>
> The poor fellow was falling, falling, but the female within the nest screamed a number of times. I wondered whether the interloper could seduce the male, but from subsequent observations it seemed unlikely that she would. The male returned again to the nest hole, and a few minutes later was in the upper part of the tree knocking about on dead branches until he dislodged a piece of bark. He clamped his bill on the bark until it was largely fragmented. Then he moved toward the foreign female. If he presented the bark [a cherished play object among hornbills] one would suppose that she had some attraction for him. After a moment, however, he changed his direction, flew down to the big limb below, bent over the nest hole, and gave the token to his mate, accompanied by a feeding chuckle. Subsequently he returned to perch quietly within eight feet of the intruding female. At 7.30 a.m. the two of them flew away together. As the nesting season progressed, he became less tolerant of her intrusions. . . . On February 3 I again watched her fly in behind the male and alight on the nest tree, making considerable noise. The male stopped feeding his mate, swooped at the interloper and drove her down toward the ground. However, when he flew away, she followed a short distance behind.

The vampire was hard to discourage. A few days later she was observed at the entrance to the nest, trying to break the wall with her beak. Probably there was a sex murder case in the making. But "after five minutes the male arrived and . . . drove the foreign female to another tree, flying at her so hard that he knocked leaves from intervening branches. He returned to his nest with a small stick held like a cigar. His mate, who had remained silent, now began her wailing screeches. . . . The intruding female, persistent as usual . . . had followed the male back to the nest tree. In a few minutes he flew at her again, flying faster than hornbills usually do as he chased her from one tree to another." But his ordeal of bachelorhood was nearly over. Five days later mother and young emerged from the nest. "The pair of hornbills were perched side by side on their nest tree. Not long after I heard a great flutter of wings. I looked back to see both members of the pair pursuing a foreign female. . . . When the parents later came to our garden, she did not follow."

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